ENVIRONMENTAL GEOLOGY NOTES

JUNE 1971 • NUMBER 47

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*UNIVERSITY OF WISCONSIN
GEOPHYSICAL AND POLAR RESEARCH CENTER CONTRIBUTION 264*

ILLINOIS STATE GEOLOGICAL SURVEY

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ABSTRACT

Sedimentary units 1 foot (30 cm) or more thick were identified on high-resolution, sub-bottom, seismic reflection profiles taken in southern Lake Michigan along a 400-mile (644 km) cruise route aboard the R. V. INLAND SEAS in June, 1970. Beneath the soft sediments that floor the lake, glacial till was clearly identifiable, as was the irregular surface of underlying Paleozoic bedrock. Gravity cores were taken along the profile track and used to correlate the acoustically reflecting horizons and the stratifications in the sediments. The geophysical record thus provided a continuous cross section that permitted detailed correlation between the widely spaced cores.

Three main sedimentary units were recognized in most of the seismic profiles: lacustrine clays (Lake Michigan Formation), glacial deposits (Equality (?) and Wedron Formations), and Paleozoic bedrock. Three separate episodes of sedimentation in the Lake Michigan Formation also were recognized. The oldest is recorded by a sequence of reddish brown clay (Sheboygan and South Haven Members) that is thickest in the northwestern part of the southern lake basin and pinches out toward shore. The next higher episode is represented by brownish gray to gray, silty clay (Winnetka and Lake Forest Members) that also pinches out shoreward and overlaps the lower unit. The youngest episode (Waukegan Member) is characterized by dark gray silt and silty clay that overlap the lower units. It is thickest in a narrow belt along the eastern side of the lake and has a delta-like cross section in places.

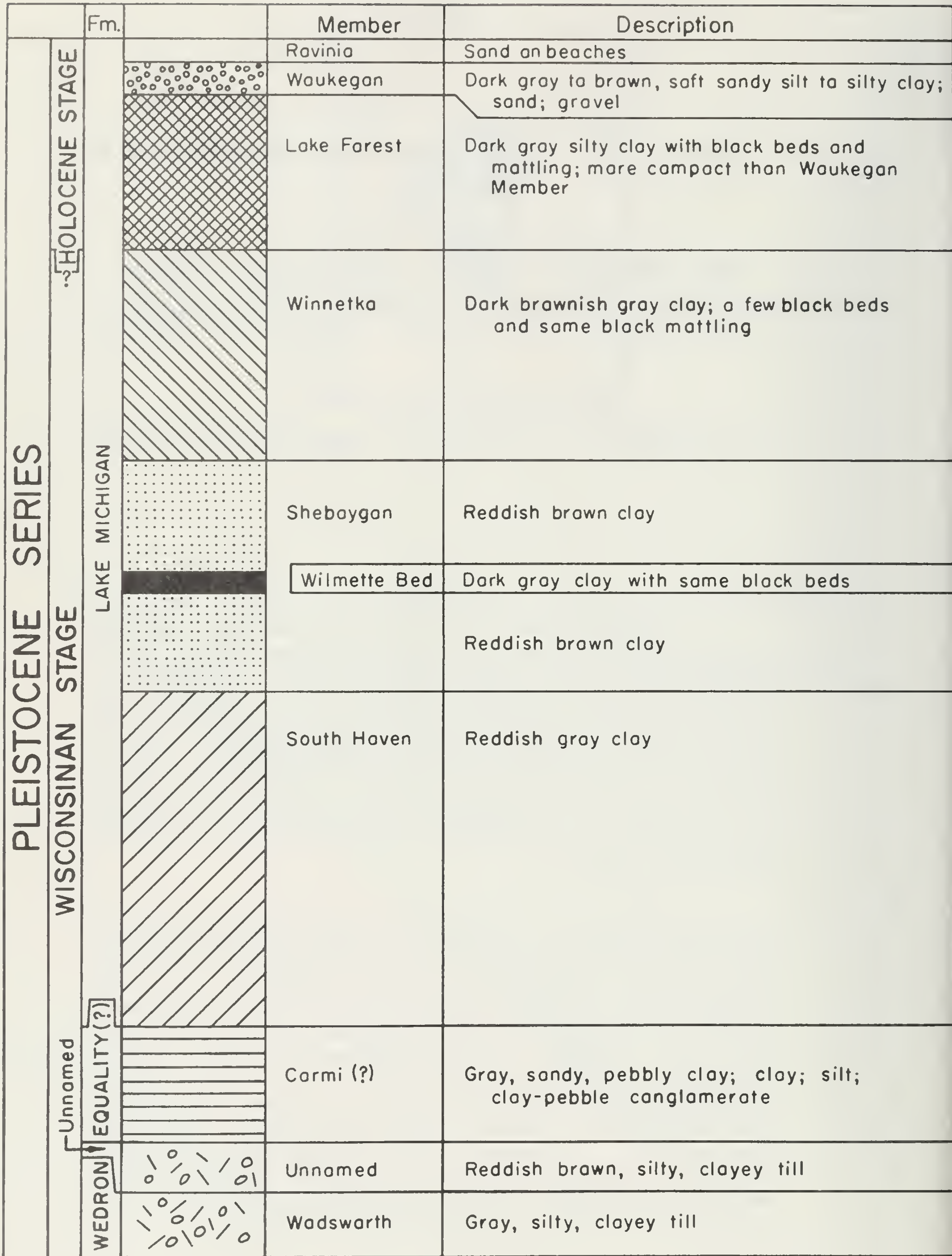


Fig. 1 - Late Pleistocene sediments underlying southern Lake Michigan.

INTRODUCTION

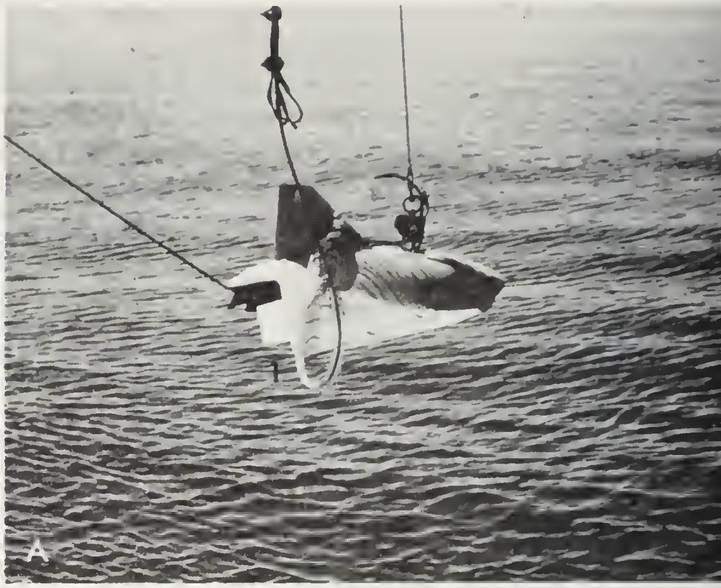
A study combining high-resolution, sub-bottom, seismic reflection profiling with gravity coring of bottom sediments in southern Lake Michigan was conducted in June 1970 by the Illinois State Geological Survey and the Geophysics and Polar Research Center, Department of Geology and Geophysics of the University of Wisconsin, Madison. The studies were made on board the University of Michigan research vessel *INLAND SEAS* and are part of a continuing program of investigation of the Lake Michigan sediments.

The Geophysics and Polar Research Center has developed a sonic geophysical technique for bathymetric and sub-bottom studies in connection with the University of Wisconsin's Sea Grant Program, begun in 1968. This technique has been used extensively in Green Bay (Moore and Meyer, 1969), and in June 1970 it was applied to southern Lake Michigan.

Previous studies of Lake Michigan sediments (Hough, 1935, 1958; Gross et al., 1970; and Lineback et al., 1970) have relied on gravity cores taken from widely separated sample stations. The cores have provided data for erecting a stratigraphic framework for the sediments in Lake Michigan (Lineback et al., 1970) (fig. 1). Because of the scattered distribution of sample stations, however, variations in distribution and thickness of the sediments could not be explained.

A sonic technique applicable to lake surveys was developed to provide a method for correlating the sediments found in core samples with their associated acoustic properties and to trace quickly the stratigraphic horizons between core locations while the ship was underway. The sonic technique applied in Lake Michigan permitted us to inspect the bottom at about 5-foot (1.5 m) intervals along the ship track while we traveled at a speed of 12 miles per hour (19.3 kmph). In previous coring programs, sampling stations were no closer than 4 miles. When the profiling technique is used, the bottom and sub-bottom are measured acoustically about 4,000 times in a 4-mile run.

Four hundred miles (644 km) of continuous seismic profiling were recorded in southern Lake Michigan between June 14 and June 20. The recordings provided "instant" cross sections of the acoustic reflections between coring sites and produced an abundance of detailed information on thickness, distribution, and stratigraphic relations of the sediments. Sediment cores were collected along the seismic traverses, and their location was marked precisely on the seismic profiles. Acoustic energy generally reached reflecting horizons deeper than the coring device could reach, penetrating to bedrock as much as 250 ft (76 m) below the surface of the unconsolidated sediments. The most important reflecting horizons have been correlated to stratigraphic units differentiated in the sediment cores. The cores are 1 7/8 inches (47 mm) in diameter, range up to 18.9 ft (5.76 m) in length, and were taken by the method described by Gross et al. (1970) and Lineback et al. (1970). Descriptions of cores are included in the appendix. Preliminary results of the seismic study were reported by Meyer et al. (1970) and by Lineback et al. (1971). Geochemical studies of these same sediments have been reported by Shimp et al. (1970, 1971), Schleicher and Kuhn (1970), and Ruch et al. (1970).



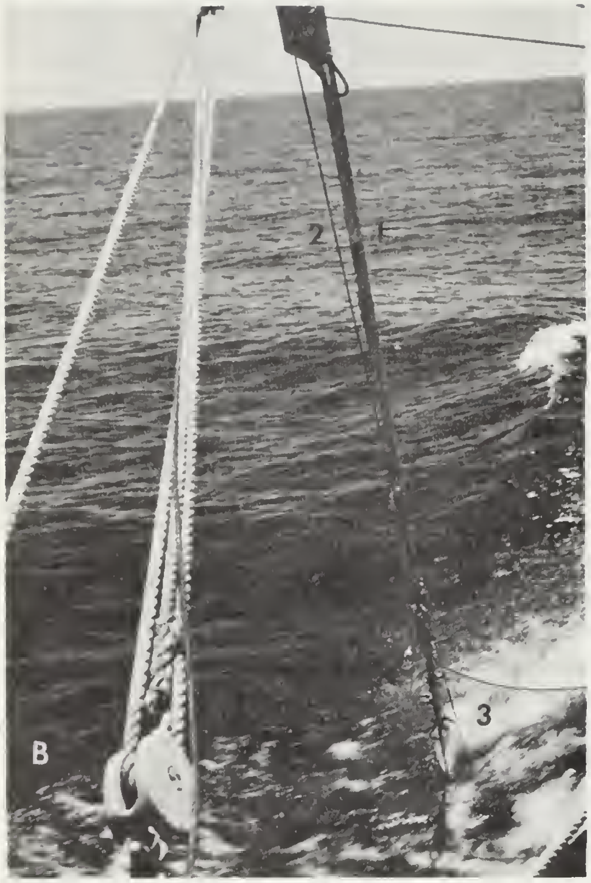


Plate 1A. The geophysical "fish" suspended from the main boom of the R. V. INLAND SEAS. The fringed cable (1) contains electrical circuits.

B. Flexible shock cord (1) attached to the "fish" while it is being towed; (2) lifting cable; and (3) fringed electric cable.

C. The INLAND SEAS entering port of Waukegan, Illinois, with "fish" under tow (1). The portable electronics laboratory (2) is on the port foredeck of the ship.

The seismic equipment was provided and operated by the Geophysical and Polar Research Center, University of Wisconsin, Madison. R. P. Meyer was in charge, aided by W. L. Unger, T. R. Meyer, and L. A. Powell. Besides the authors and the above, M. P. Stephens, N. J. Ayer, R. G. Weber, and H. V. Leland composed the scientific crew for the cruise.

We appreciate the valuable aid and assistance of Captain Richard Thibault and the crew of the *R. V. INLAND SEAS* and of the University of Michigan Great Lakes Research Division, which operates the ship under sponsorship of the National Science Foundation.

This research was supported in part by the University of Wisconsin's Sea Grant Program, which is a part of the National Sea Grant Program maintained by the National Oceanic and Atmospheric Administration of the U. S. Department of Commerce. The report will also be distributed by the Wisconsin Sea Grant Program as Reprint WIS-SG-71-317.

GEOPHYSICAL OPERATIONS

Basic to the operation of the sonic profiling technique is a hydrodynamically shaped depressor ("fish") towed from the main boom of the ship. The fish contains both electrically driven sonic sources and receivers that convert the returning sonic signal into an electrical one. The fish is designed to "fly" in a stable position about 10 feet (3 m) below the surface while being towed (pl. 1A). The acoustic signals were induced and received by electronic gear housed in a portable laboratory located on the deck of the ship.

As in fathometer techniques, a sonic pulse was directed at the bottom and the echoes were recorded *vs.* elapsed time. The high-resolution process differs from fathometer techniques in that the pulses are shorter and stronger and the sub-bottom echoes are recovered by greatly increasing the gain of the receiver after the bottom pulse is received. In addition, the timing is more precise and the recorders are more stable.

To obtain resolution of about 1 foot (30 cm), the resolution used in this study, the pulse length must be less than 1 foot. This implies that the time length of the pulse in water having a sonic velocity of 5 feet (1.5 m) per millisecond, for example, must be less than one-fifth of a millisecond. The time length of the pulse employed in our survey was one-seventh of a millisecond and consisted of one cycle of a 7 KHz sinusoid pulse. High resolution also implies that time stability of the recorder must be at least better than one-tenth of a millisecond. The recorders employed were stable within 50 microseconds. A continuous check on stability was provided every one-twentieth of a second by pulses of 10 microseconds duration that are produced by a precision chronometer and that provided the vertical time scale for the record (fig. 2). Unlike most recorders, in which the time scale is printed on the recording paper or generated by the moving element of the recorder (belt, drum, or helix), the time scale in the system we used is electronic and independent of the mechanical recorder system.

Another requirement for maximum resolution, for which there was substantial refinement during the 1970 cruise, centers on eliminating from the bottom and sub-bottom records the vertical motion of the transducers caused by

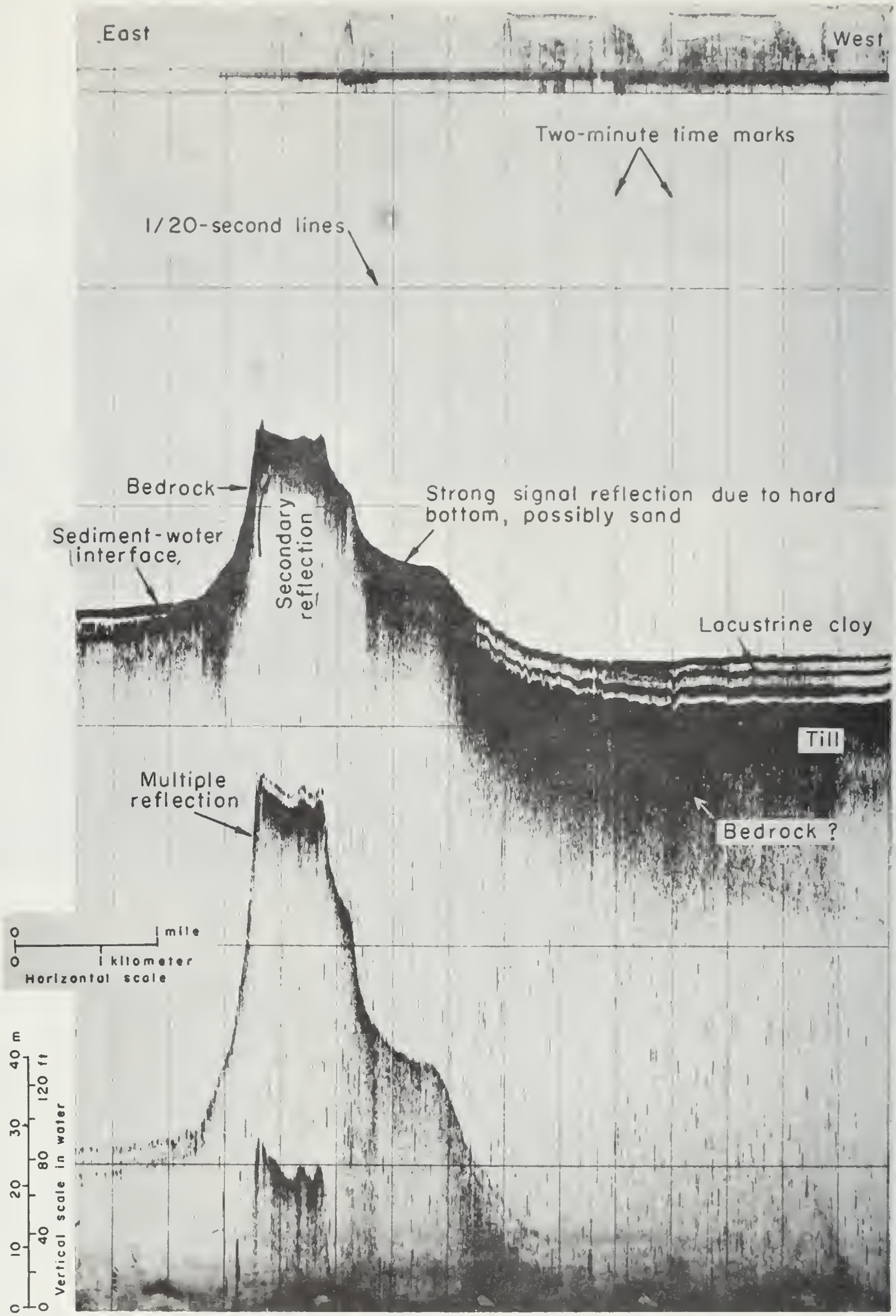


Fig. 2 - Record of a high-resolution seismic profile showing the various reflecting horizons and lines marking vertical and horizontal scale. Bedrock reflections under lacustrine clay and till are weak because most of the acoustical energy was reflected and/or absorbed by the overlying sediments. The bedrock hill is located about 26 miles (42 km) east of Milwaukee, Wisconsin.

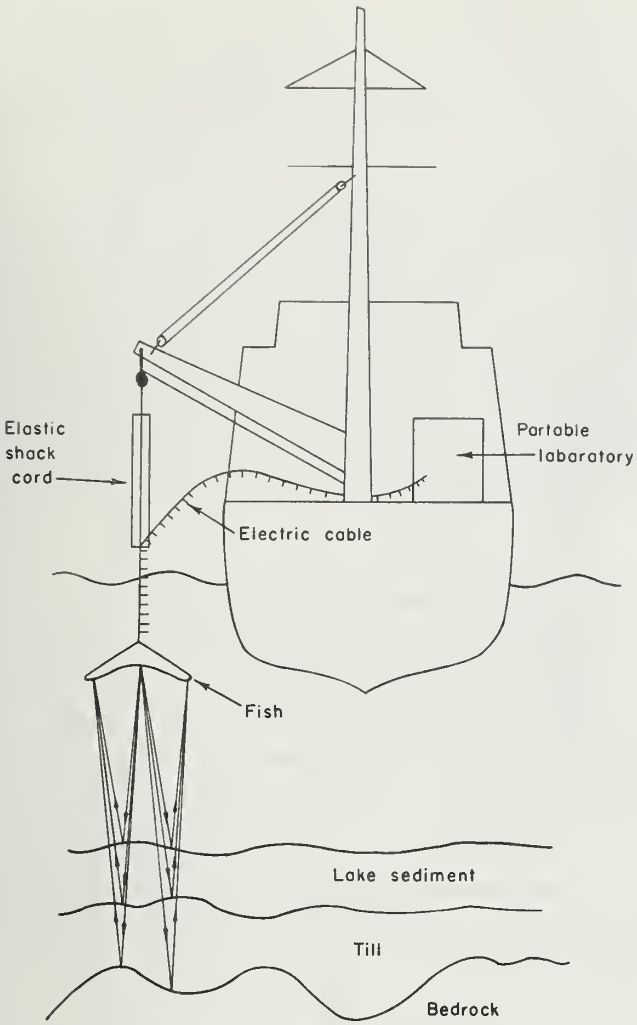


Fig. 3 - Diagram of the foredeck of the R. V. INLAND SEAS showing the arrangement for towing the geophysical "fish." The portable laboratory was located on the port side of the main hatch. The "fish" was towed from the main cargo boom on the starboard side of the ship.

the ship's motion. The fish containing the transducers is suspended by shock cord from the ship's boom and flies at 10 feet (3 m) below the surface (pl. 1A,B,C; fig. 3) to reduce the effect of the ship's roll. In addition, a pressure sensor was mounted in the fish to monitor the depth, and electronic delays proportional to fish depth were applied to modify the time of the outgoing pulse to simulate constant depth for the fish and hence provide a constant datum.

Equipment and Operation

A portable laboratory (7 x 6 x 12 feet) housed the profiling equipment (pl. 1B; fig. 3) on the ship. The laboratory is self-contained, needing only the support of the ship for towing the fish and for electric power (10 KVA). Advantages of a portable laboratory are that no indoor ship space is required and, more important, that the electronic equipment, which is reasonably complex, need not be installed in ship space before the cruise, thus minimizing set-up time and forestalling all manner of electronic problems.

The heart of the electronic equipment is a modified sonic transceiver made by EDO Corporation (model 415-3.5-7). The high-resolution sonic pulse transmitter can generate pulses of variable length and of either 3.5 or 7 KHz at an equivalent continuous power level of up to 1400 watts. The fish containing the transducer, a common sonic pulse generator and receiver, was connected to the transceiver through a towing cable suspended from the ship's boom, as shown schematically in figure 3. The signals received from the transducer are amplified and processed by using time-varying gain circuitry, and then are recorded on teledelphous (dry electrically sensitive) paper on drums.

To assure recognition and accurate measurement of the sediment surface of very soft unconsolidated sediments, sonic pulses of higher frequency than those available from the high-resolution system were employed. These were provided by a 40-KHz fathometer (a modified Raytheon DE 721) whose transducer also

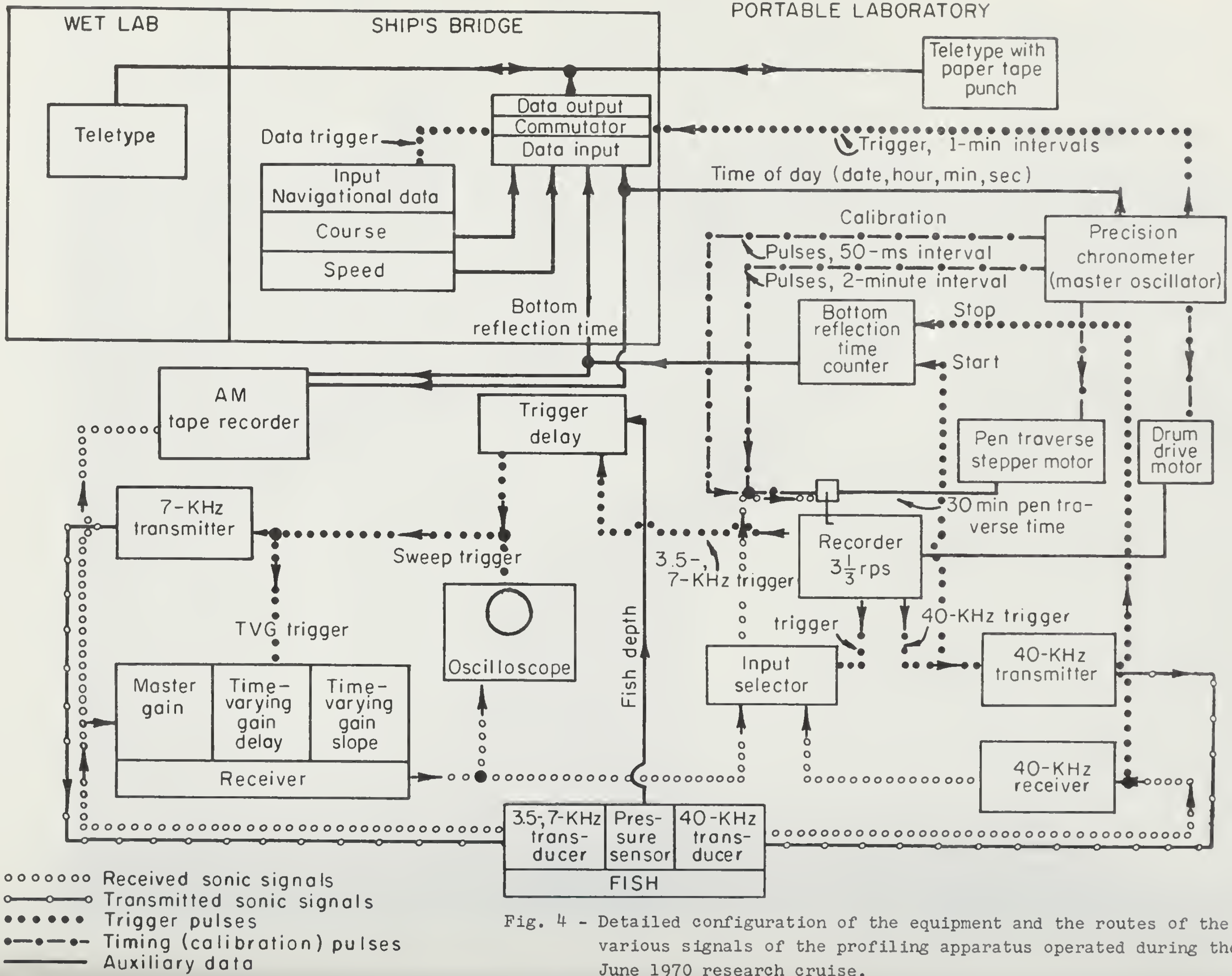


Fig. 4 - Detailed configuration of the equipment and the routes of the various signals of the profiling apparatus operated during the June 1970 research cruise.

was located in the fish. Return signals were, at least in shallow water, recorded on the same record as the lower frequency high-resolution data. The combined information from the 40-KHz fathometer and from the depth of the fish provided an accurate measurement of the bottom.

To eliminate much of the routine post-cruise record processing and bookkeeping, such bathymetric data as elapsed time from outgoing to returned bottom pulse, fish depth, and navigation information were recorded at 2-minute intervals *vs.* date and time of day in digital form on paper punch tape. Information such as station number, weather, and sea conditions were entered onto the paper tape from teletype machines located in the portable electronics laboratory and in the ship's laboratory. Navigational data from the bridge were recorded on a special console and provided a running annotated log. In addition to the paper tape record, high-resolution data and time were continuously recorded on magnetic tape so that complete sonic data would be preserved for further processing and study.

The main components of the profiling system are illustrated in figure 4. Figure 5 shows the system as it was operated during the cruise. The drum recorder merits special notice, inasmuch as it initiated the transmitter's pulse as well as recorded the data. The motor rotating the recording drum was slaved to a master oscillator-chronometer. The same oscillator provided a timing mark at one-twentieth of a second intervals, which appear as horizontal lines on the drum record (fig. 2) and represent the scale against which reflection times are measured. The lead screw for the pen that provided the distance scale was rotated by a stepping motor, also slaved to the master oscillator. At 2-minute intervals, one sweep of the pen was darkened, putting a vertical line on the record to provide a time scale related to the ship's position. Since the speed of the ship was 12 mph (19.3 kmph), 2.5 of these vertical divisions (5 min) equal 1 mile (1.6 km) of distance.

The time-varying gain (TVG) in the EDO receiver was arranged to allow the operator to "program" logarithmically increasing amplifier gain, starting at a specified time after the output pulse. This allowed increasing amplification of later sub-bottom signals with no distortion of the strong first returns.

The transmitted pulse triggered the horizontal sweep of an oscilloscope (HP model 521A), and each reflected signal was temporarily stored on the view screen. The operator could thus visually cross-correlate return signals from several pulses and adjust the over-all system response to the characteristics of the record.

The teledelphous paper used for the recordings is capable of reproducing 10 distinct shades of gray. The shades are used to represent all signals, from the smallest amplitude (white), to the largest amplitude (black), and they limit the dynamic range of the recordings to 20 decibels (db), or a factor of 10. The range of variation in raw signal size is at least 100 times this (60 db). This limitation was overcome principally by use of the TVG, and by recording the data on a multichannel magnetic tape that provided wider dynamic range (60 db).

Interpretation and Analysis

In shallow water the amplitude of the signal returning from the bottom is proportional to two factors dependent on the physical setting. One is

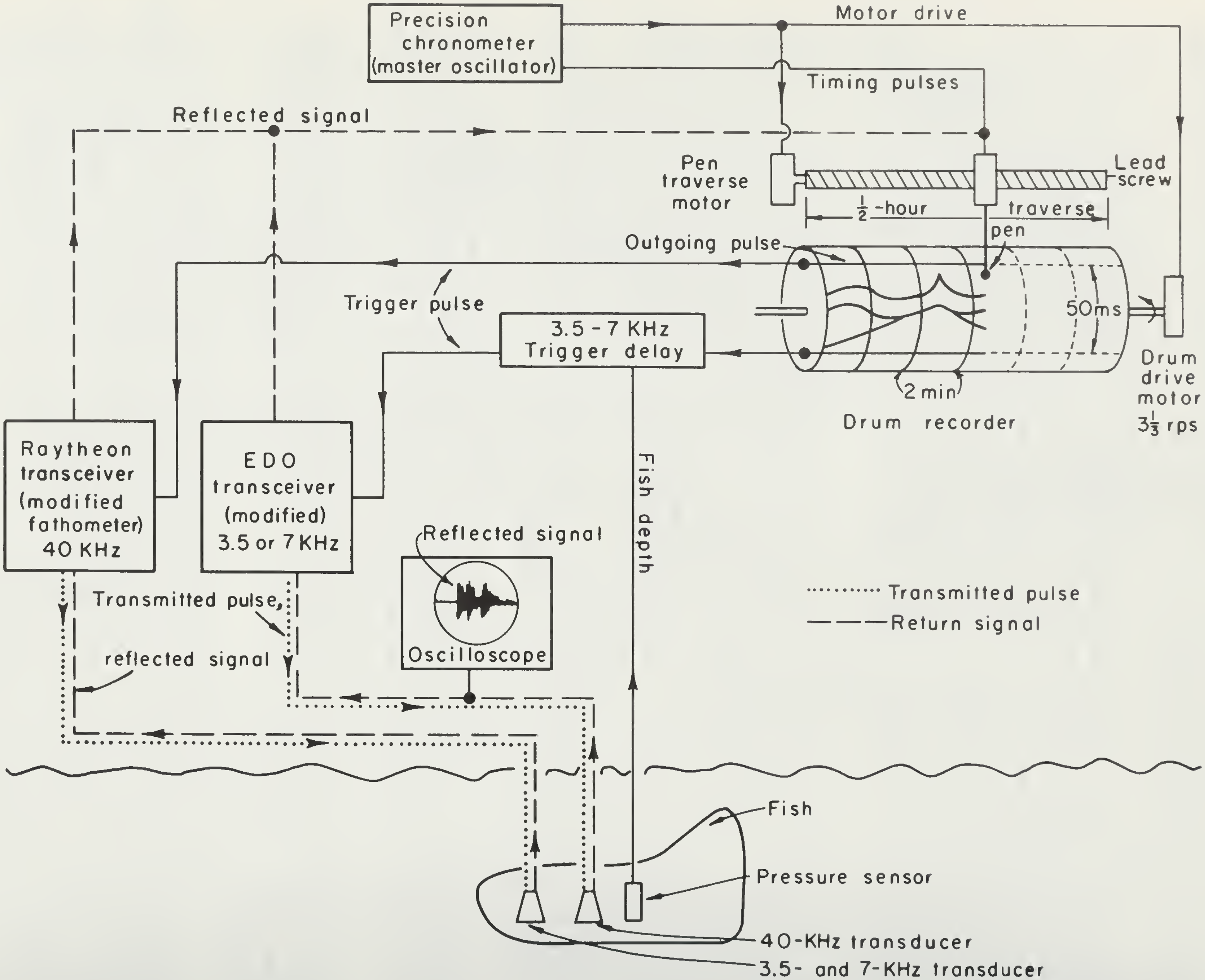


Fig. 5 - Simplified block diagram of the main components and configuration of the seismic profiling system used during the June 1970 research cruise.

the geometrical spreading of the pulse, which reduces the amplitude in proportion to $1/(2d)^2$, where d is the distance from the transducer to the reflector. The second is the reflectivity (R), a factor dependent on the acoustic impedance contrast associated with the ratios of velocity (v) density (ρ) products of the water and the sediments.

$$R = \frac{v_1 \rho_1}{v_2 \rho_2}$$

In the sub-bottom sediments, the situation controlling the returned energy is more complicated. The strength of these returns depends not only on the local reflection coefficient, but on the amount of downward-traveling energy remaining after the sonic pulse has been reflected by overlying interfaces, and on how much of the remaining energy is absorbed by overlying materials. Both absorption and reflectivity factors have a strong effect on the quality of seismic records from the Great Lakes. Physically hard bottoms have high acoustic impedance and severely limit the energy penetrating below them. Records taken over hard bottoms show powerful returns and multiple reflections from the highly reflective sediment-water interface (fig. 2). Strong absorption in soft sediment also limits deeper penetration and is recognizable by a lack of sharpness at the interface and by a lack of multiple arrivals.

Soft lacustrine sediments are typical of large areas in southern Green Bay and southeastern Lake Michigan, where they are called the Lake Michigan Formation (fig. 1). They provide weak surface and near-surface echoes and ideal conditions for penetrating to and recognizing deeper layers (fig. 2). These sediments seem characterized by few internal features. Below them, in many areas, apparently closely "layered" zones have been penetrated. The few cores that have penetrated the layered sediment show it is lacustrine silt and clay that in places is more compact and coarser grained and has a lower water content than the Lake Michigan Formation. The closely layered sediment in southern Lake Michigan was assigned to the Equality Formation (Lineback, 1970) (fig. 1). Still lower, strong reflections are returned from horizons interpreted to be glacial till and bedrock surfaces (fig. 1).

The depth of penetration and the amount of useful information obtained from high-resolution seismic profiling vary greatly. In areas where the bottom sediments are till, sand, or bedrock, only bottom echoes and multiple reflections are recorded. Gravity coring commonly fails in such areas, in some cases with disastrous consequences to the coring apparatus. Consequently, grab samples and rock dredgings are used to identify the type of bottom sediment in such places. In areas where the sonic technique predicts soft bottoms, gravity coring has always been successful. In a few areas, high sonic energy absorption has been encountered even though grab samples have indicated soft bottoms and the bottom has been cored successfully. The causes of such signal loss are still not clear but are tentatively correlated with sediment that is rich in organic matter or contains gas bubbles.

The deepest sonic penetration achieved in this study is about 0.1 second, which is equivalent to about 250 feet (76 m) if we assume that the materials penetrated have the same sonic velocity as water. For the relatively short

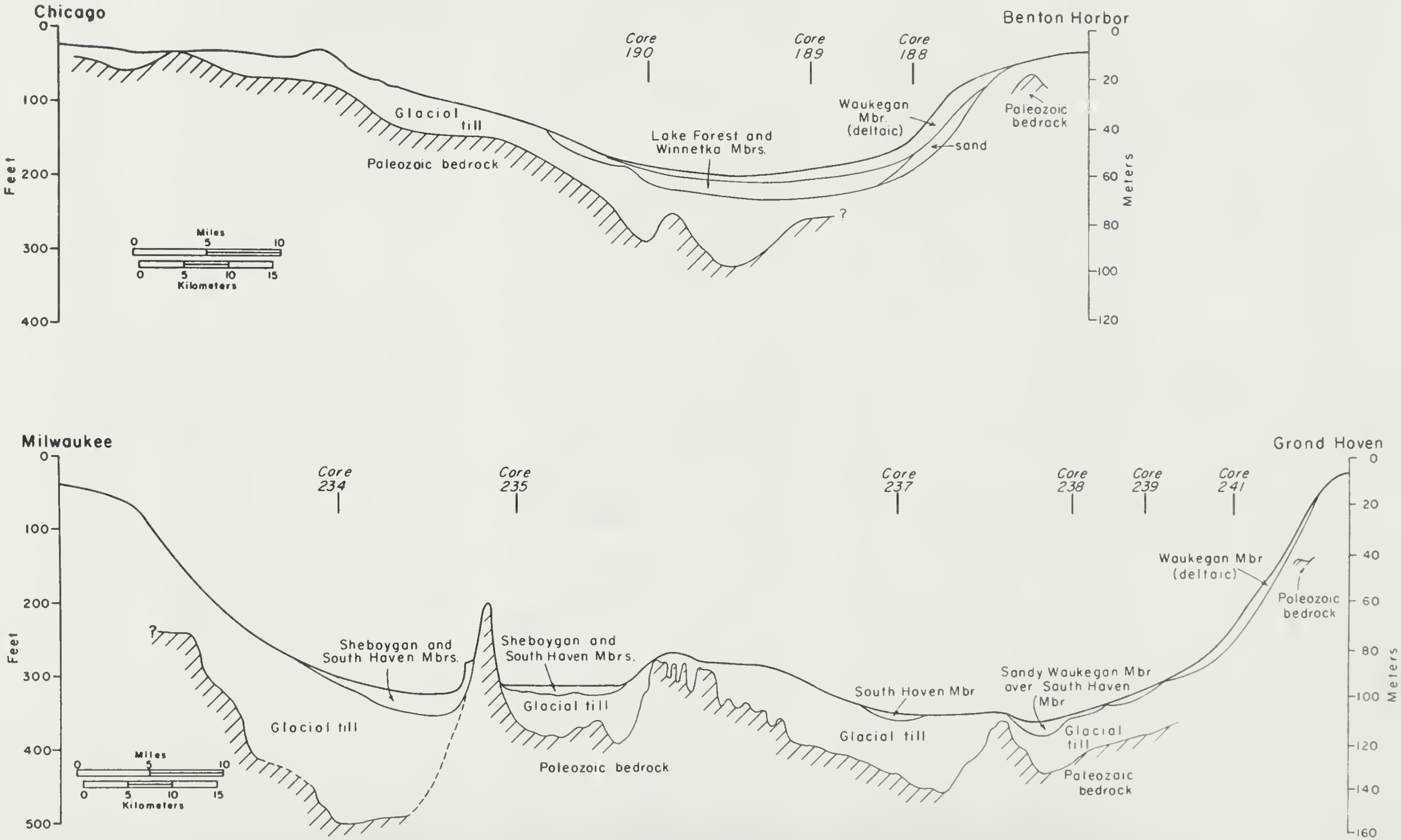


Fig. 6 - Interpretative cross sections based on geophysical profiles. See figure 10 for location of cross sections.

maximum lengths of cores of the soft, water-saturated, lacustrine clay of the Lake Michigan Formation thus far obtained (18.9 ft; 5.76 m), this assumption has worked well. The predicted depths to prominent reflecting horizons have been very close to the observed depths. The main acoustic reflecting horizons correlate with changes in physical properties, such as texture, water content, and compaction. Greater accuracy in determining sediment thickness will be possible when continuous velocity measurements can be taken of materials within the cores to determine what variations in sonic velocities occur within the sediment column. Only then can the full potential of the sonic method be realized.

All measurements of thickness in this study, however, are based on the assumption that the velocity of sound in all the measured sediments is the same as in water. As mentioned above, coring demonstrates that this assumption is fairly accurate in soft, water-laden sediments. The more consolidated till and bedrock units, however, have different sonic properties and the thicknesses reported for them may be in error by a factor of up to two; in other words, they may be thicker than reported.

The high-resolution profile data provide needed correlation between core samples. The variation and intricacy of the stratigraphic record now revealed makes clear the value of this intercore information.

SEDIMENT DISTRIBUTION AND THICKNESS

The seismic records in this study clearly show that lake clays, glacial drift, and bedrock under Lake Michigan can be readily distinguished by geophysical means. In addition, the layers of lacustrine sediment have sufficiently different acoustical properties to allow a number of the stratigraphic units recognized by Lineback, Ayer, and Gross (1970) to be identified and plotted between coring stations (figs. 6-8). For example, the Chicago to Benton Harbor traverse (fig. 6) shows that glacial till thinly mantles bedrock for a considerable distance east of Chicago. In the deeper water, lake clays of the Lake Michigan Formation can be identified and can be seen to thicken eastward until shallow water is reached near Benton Harbor. On the same figure, the Milwaukee to Grand Haven traverse shows a spectacular development of bedrock topography along the mid-lake high. Till is very thick (184 ft; 56 m) in the area east of Milwaukee, but is absent over some bedrock hills. In the same area, the Lake Michigan Formation occurs in low places on the till and it also occurs along the eastern shore.

Bedrock topography is also prominent along the traverse extending from Benton Harbor to Grand Haven (fig. 7). The Lake Michigan Formation is thin or absent in the near-shore areas, and is thickest on the slope descending into the basin. The Chicago to Waukegan traverse (fig. 7) shows till thinly mantling the bedrock and thin deposits of the Lake Michigan Formation in deep water. A thick accumulation of till also was found southeast of Milwaukee, as shown in the Waukegan to Milwaukee traverse (fig. 8). The seismic traverse extending east from Waukegan, then north, and finally returning to Waukegan (fig. 8) crossed the deepest water (more than 400 ft; 122 m) in the southern lake basin. Smooth bedrock topography is evident along this traverse, and the till is thin. The Lake

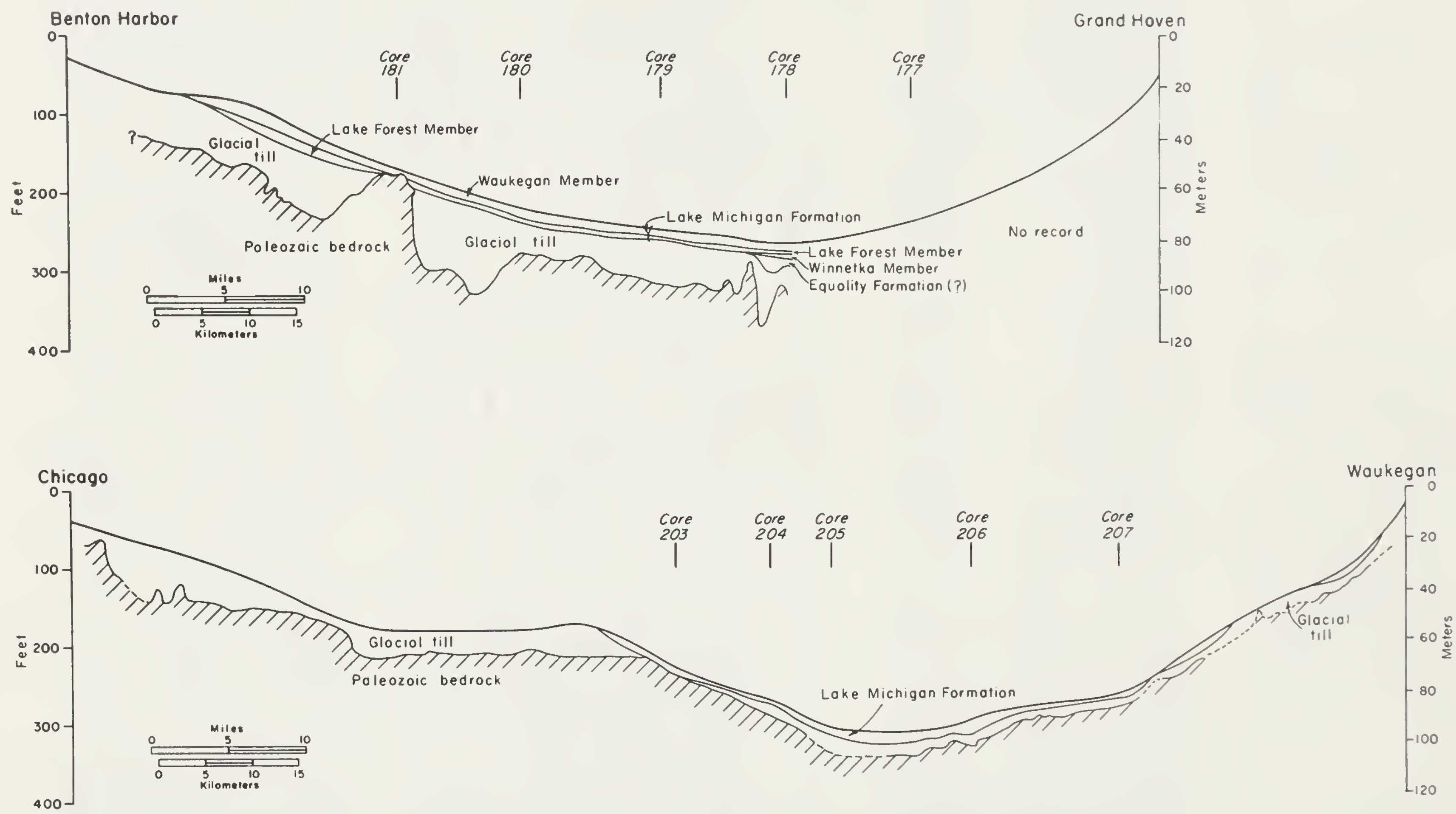


Fig. 7 - Interpretative cross sections based on geophysical profiles. See figure 10 for location of cross sections.

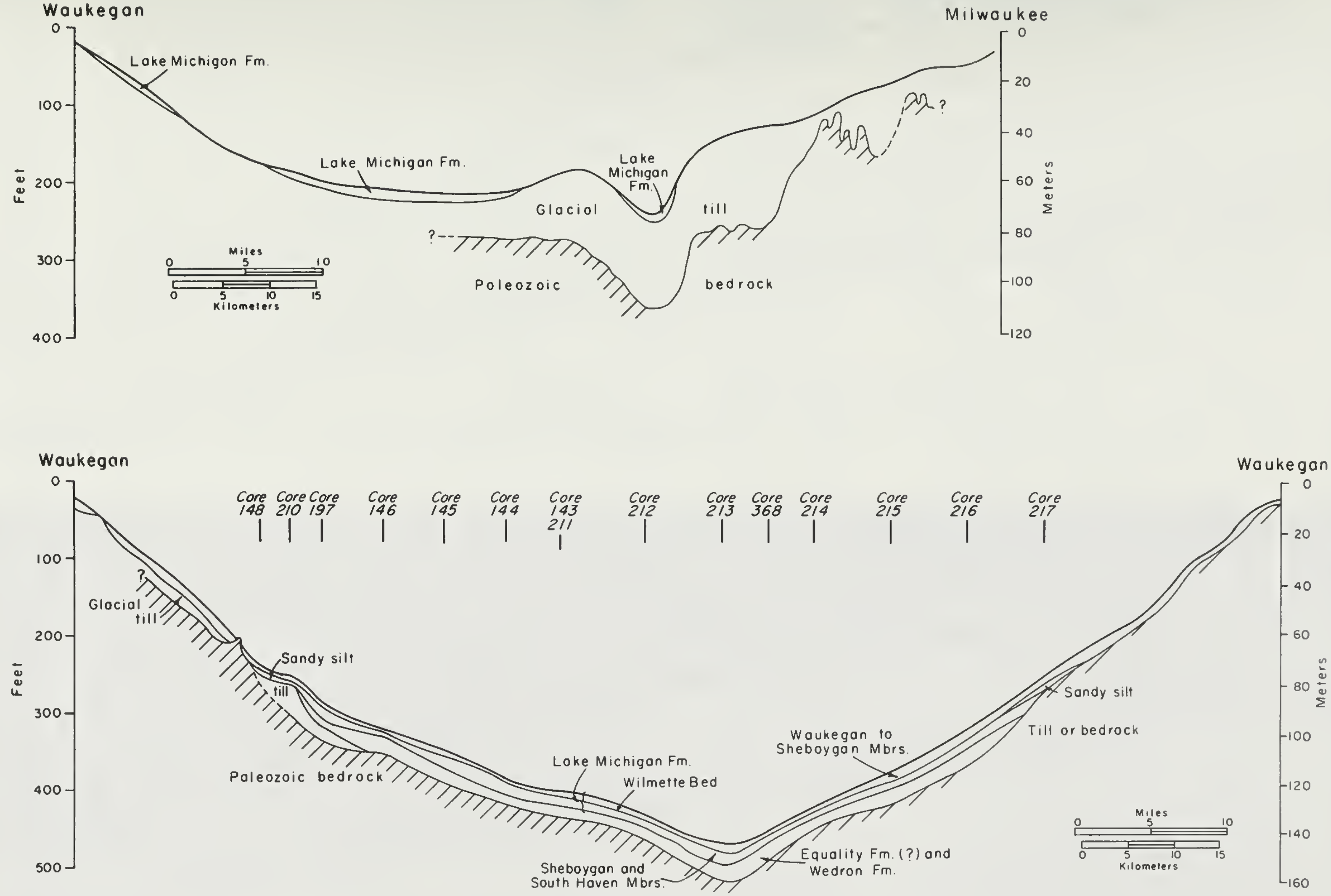


Fig. 8 - Interpretative cross sections based on geophysical profiles. See figure 10 for location of cross sections.

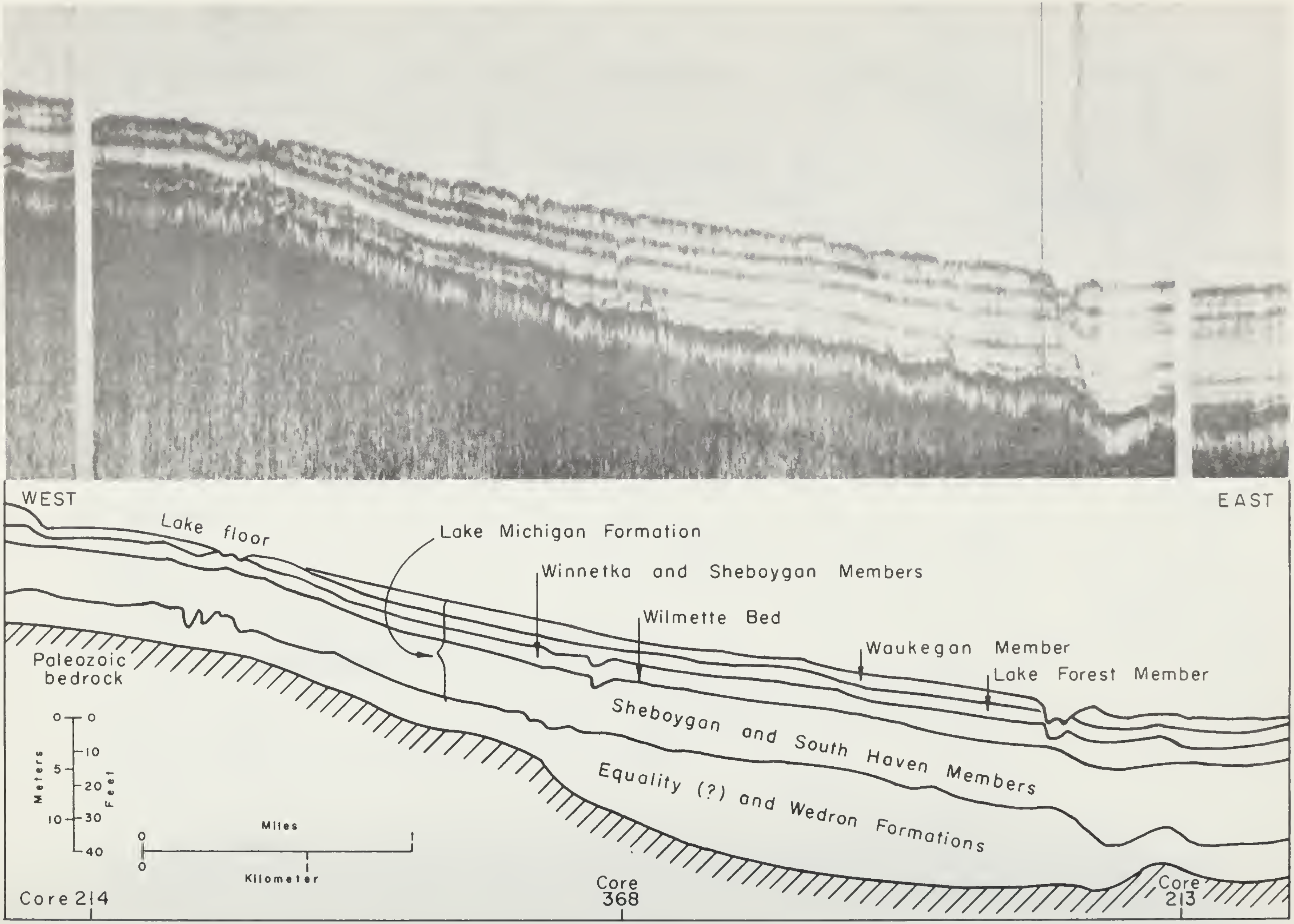


Fig. 9 - Seismic profile and interpretation of an area 35 miles (56.3 km) northeast of Waukegan (see figure 10). The closely layered Equality (?) Formation thins shoreward, as do most of the overlying units. Till (Wedron Formation) is thin

Michigan Formation is more than 32.8 feet (10 m) thick in places in the deep water near the center of the basin. The thinly layered Equality (?) Formation is thicker in the deep water than in areas of shallower water.

The Lake Michigan Formation (fig. 1) consists of soft, water-saturated clay, silt, and sand. Acoustical penetration was very good in clay and silt, but not in sandy sediments. As shown in figure 9, numerous reflecting horizons are present within the Lake Michigan Formation. Some can be traced for long distances and are related to members of the formation. The formation underlies lake waters in most of the southern basin except in a few areas where bedrock highs are present, in a narrow shallow-water band around the lake, and in an extensive shallow-water shelf area in the southwestern part of the lake (fig. 10). Glacial deposits that elsewhere occur beneath the formation commonly occur at the lake floor surface where the Lake Michigan Formation is absent. The formation is as much as 39.4 feet (12 m) thick in a narrow band along the eastern shore of the southern lake basin and ranges between 25.2 and 36.1 feet (8 and 11 m) thick in the northwestern part (fig. 10). Where the Lake Michigan Formation is less than 1 foot (30 cm) thick it does not show on the geophysical records.

In southwestern Lake Michigan, east of Chicago, the glacial till is overlain in places by thin silt and sand that are correlative with the Waukegan Member of the Lake Michigan Formation. Also above the till in that area are outwash gravels and sands and lag gravels that are not part of the Lake Michigan Formation. Between the zero isopach and the shore, in figure 10, the Lake Michigan Formation cannot be recognized on geophysical records.

Underlying the Lake Michigan Formation in many places are glacial lacustrine sediments that were assigned to the Equality Formation by Lineback et al. (1970). Willman and Frye's recent classification (1970) of Pleistocene sediments in Illinois, however, indicates that the name Equality Formation might be inappropriate for units under Lake Michigan. Accordingly, the names Equality Formation and Carmi Member are used in this report with a question mark, pending further study of the nomenclature problem. Also underlying the Lake Michigan Formation and the Equality (?) Formation is glacial till assigned to the Wedron Formation (fig. 1) and an unnamed till unit that may or may not be related to the Wedron. Acoustic penetration of the Equality (?) Formation and the tills is fair to poor, although, in places, acoustic horizons within the tills can be traced for short distances. The Equality (?) generally is more acoustically layered than the tills, but it cannot always be distinguished on the seismic records. Glacial sediments differ from those of the Lake Michigan Formation by being more compact, coarser grained, and less well sorted, and by having a lower water content. The glacial deposits are very irregular in thickness and range between zero and 184 feet (56 m) in the southern lake basin. They are thickest in near-shore areas and in bedrock valleys and are thinnest in the center of the basin and over bedrock highs (figs. 6, 7, and 8). As can be seen in figure 11, glacial deposits smoothed the bedrock topography by filling the low areas, thus providing a smooth surface for deposition of the Lake Michigan Formation.

Most of the till in the southern part of the lake is blue-gray, clayey, silty till with traces of sand and pebbles that is assigned to the Wadsworth Member of the Wedron Formation (Willman and Frye, 1970; Lineback et al., 1970)

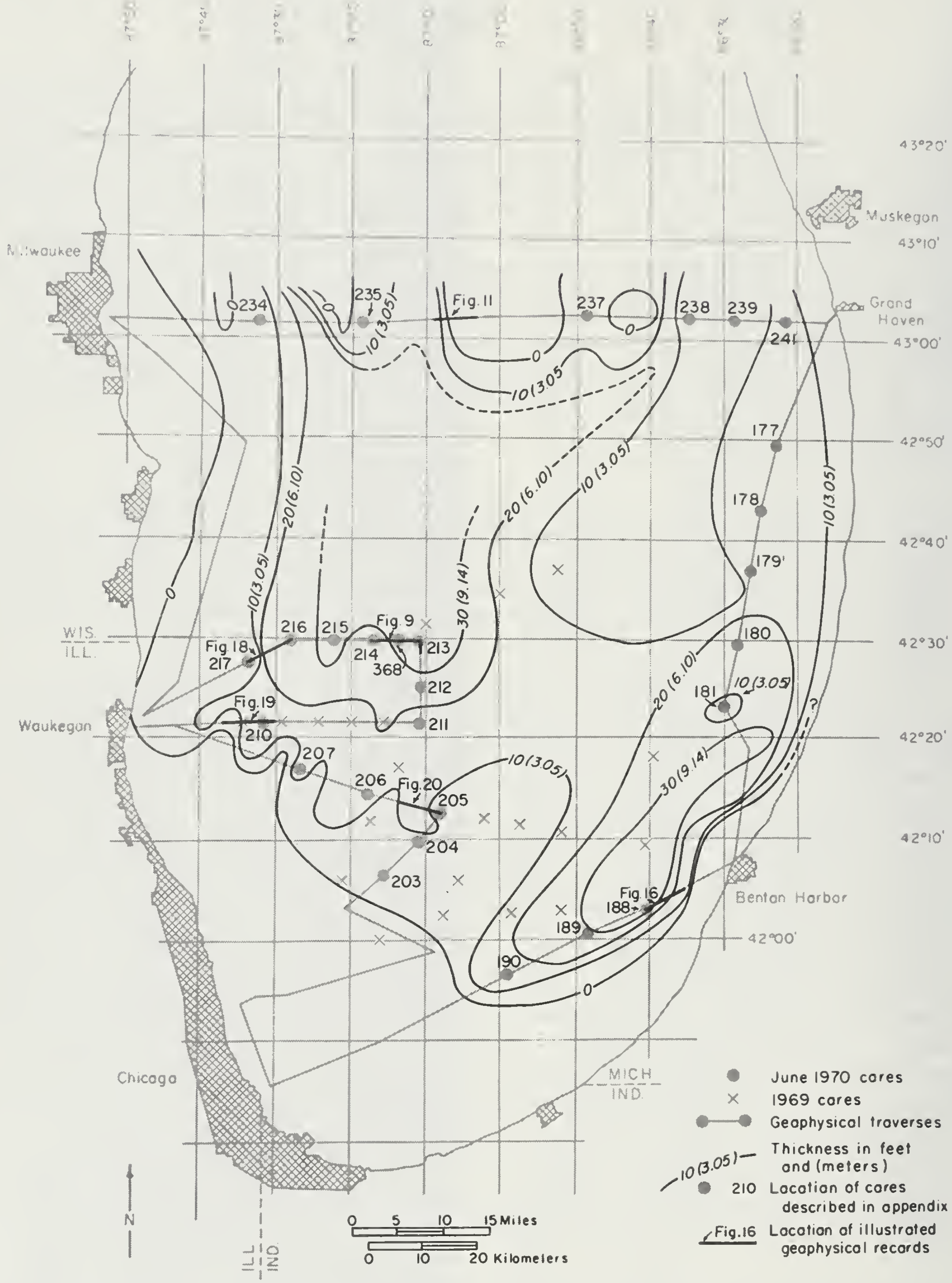


Fig. 10 - Water-equivalent thickness of Lake Michigan Formation. Isopach interval is 10 ft (3.05 m). Zero isopach marks shoreward limit of acoustically recognizable Lake Michigan Formation. Thin (< 1 ft, or 30 cm) silt, sand, and gravel, unrecognizable on the geophysical records, may overlie till where Lake Michigan Formation is absent. Locations of cores described in the appendix, lines of geophysical traverses, and locations of interpretative profiles illustrated in this report also are shown.

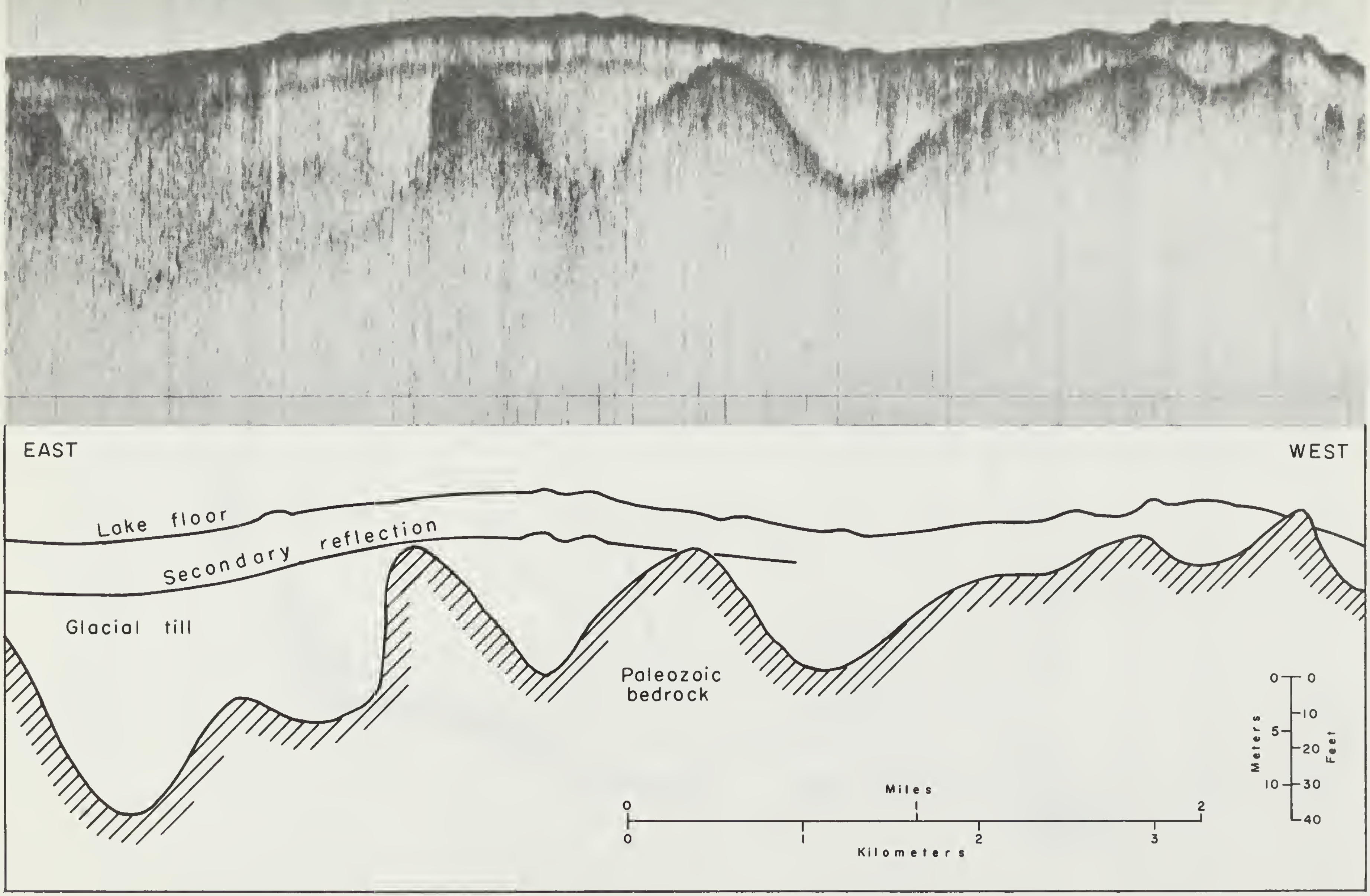


Fig. 11 - Seismic profile and interpretation of an area on the mid-lake high, located 35 miles (56.3 km) east of Milwaukee (see figure 10). The irregular bedrock surface has been smoothed by deposits of till. The secondary reflection is an echo and not a reflecting horizon in the sediment.

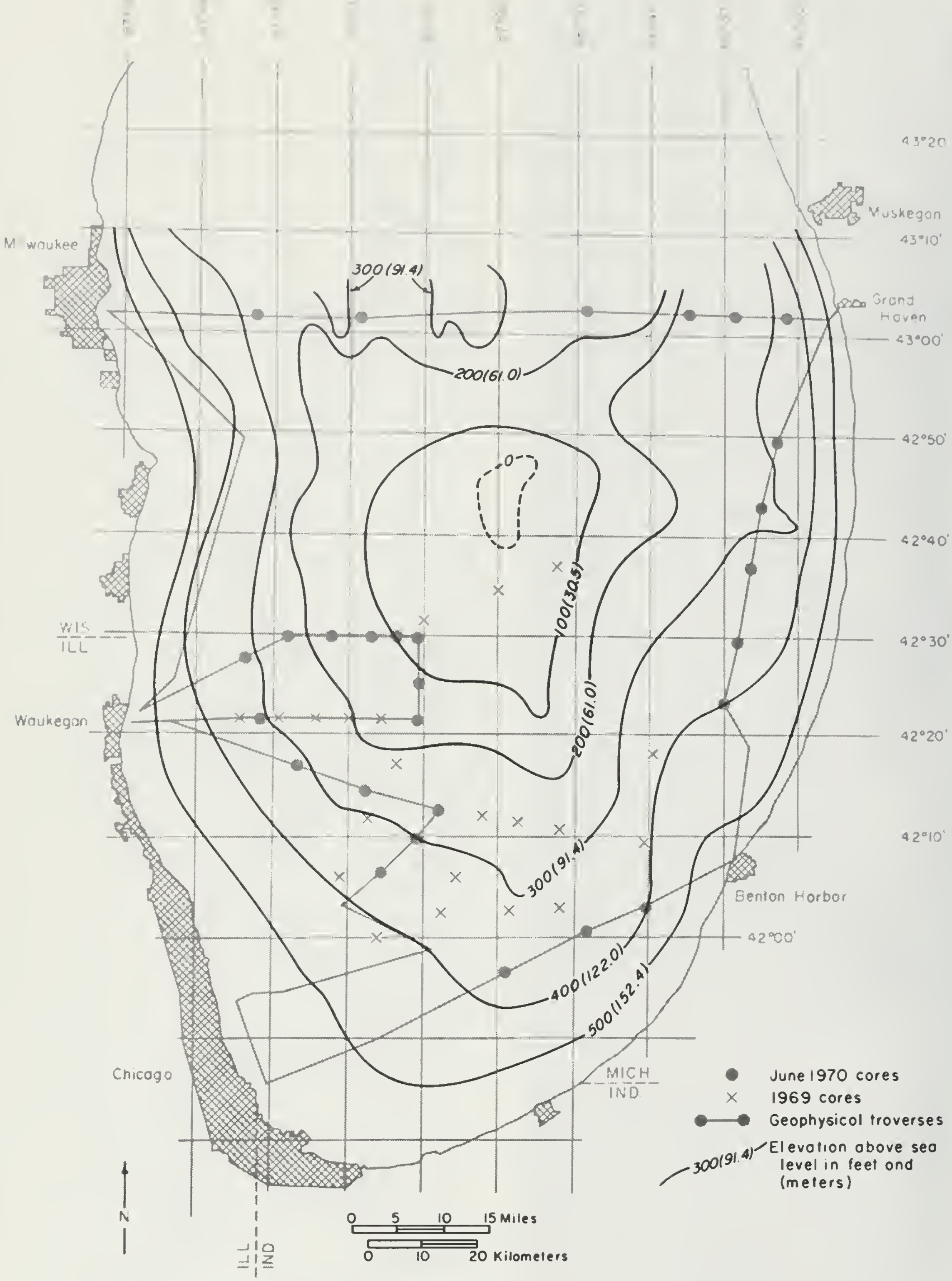


Fig. 12 - Elevation (datum mean sea level) of the surface of glacial drift in southern Lake Michigan, based on cores and geophysical profiles. Contour interval is 100 feet (30.5 m).

(fig. 1). An unnamed reddish brown till is present from Waukegan northward and is the surface till over the southern part of the mid-lake high. The till may be a previously unrecognized member of the Wedron Formation, or it may be related to tills deposited during the Port Huron or Valders glaciation.

In describing the post-glacial history of the lake basin, the topography of the surface of the glacial drift should be considered rather than that of the bedrock surface. The elevation of the lowest outlet of the southern lake basin is about 200 feet (61.0 m) above sea level on the till surface (fig. 12), whereas the elevation of the outlet on the bedrock surface is considerably lower, about 100 feet (30.5 m) above sea level (fig. 13).

Paleozoic bedrock underlies the glacial deposits. Bedrock consists of several limestone, shale, and sandstone units that form an irregular surface in many places (figs. 6, 7, 8, and 11). Acoustic waves generally do not penetrate the bedrock surface, but the elevation of the bedrock surface is easily determined from the seismic profiles (fig. 13). The bedrock floor of the southern basin of Lake Michigan extends below present sea level as a closed depression that was smoothed and eroded by the glaciers (fig. 9). Irregular bedrock topography and, in places, buried bedrock valleys are present around the margin of the basin and near the mid-lake high (fig. 11). Further evidence of glacial erosion is provided by the abundance of bedrock fragments, particularly Upper Devonian black shales, in the tills surrounding the lake. These shales were probably eroded from the central area of the southern lake basin.

LAKE MICHIGAN FORMATION

The Lake Michigan Formation is divided into several subunits, as described by Lineback et al. (1970) (fig. 1). Additional cores and seismic profiles collected during the June 1970 cruise have extended our knowledge of the thickness and distribution of the members of the Lake Michigan Formation, and the tracing of acoustical horizons indicates that there were at least three major episodes of sedimentation during the deposition of the formation (fig. 14). Each episode extended the formation closer to the margin of the basin and to a higher topographic level, and each new sediment overlapped the sediment of the lower episode towards the present shore. Sediments of each episode, in places, appear to grade laterally into silty sand near their shoreward pinchout.

The first episode of sedimentation deposited reddish gray to reddish brown clay, which has been assigned to the South Haven and Sheboygan Members. These units extend shoreward to a present elevation of 290 to 310 feet (88.4 to 94.5 m) above sea level and thicken northward. Brownish gray to gray, silty clay, referred to as the Winnetka and Lake Forest Members, was deposited to a shoreward elevation of 420 to 430 feet (128.0 to 131.1 m) during the second episode. These sediments thicken eastward. The third episode continues today and has formed a belt of sediment with a delta-like cross section along the eastern side of the lake. This episode has produced the Waukegan Member, which consists mostly of dark gray, clayey silt with some sand.

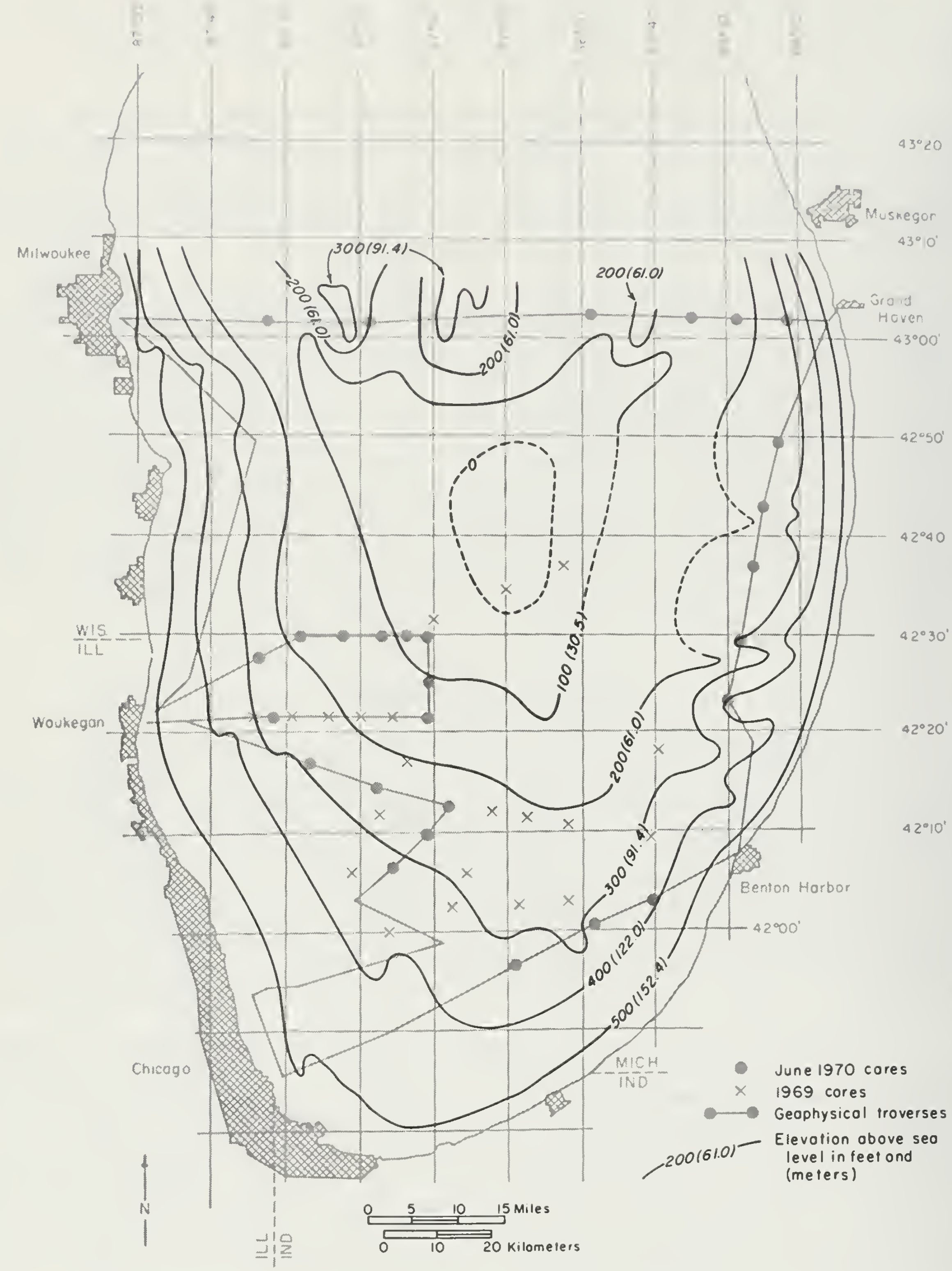


Fig. 13 - Elevation (datum mean sea level) of the bedrock surface in southern Lake Michigan, based on geophysical profiles. Contour interval 100 feet (30.5 m).

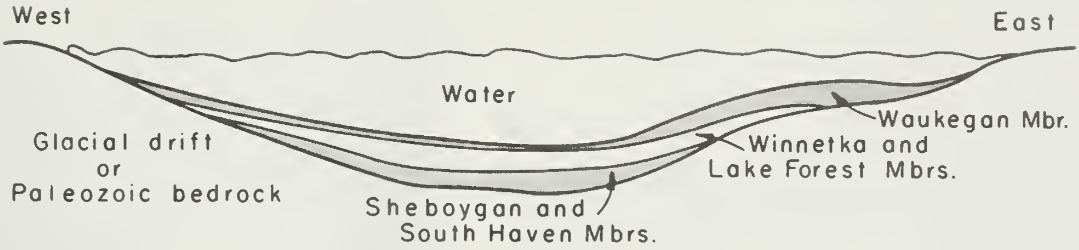


Fig. 14 - Diagrammatic (no scale) east-west cross section of the southern Lake Michigan basin showing the overlapping of sediment related to the various episodes of deposition of the Lake Michigan Formation.

Waukegan Member

The Waukegan Member is thickest (39.4 feet; 12 m) in a narrow band along the eastern side of the lake (figs. 6, 15). Acoustic horizons within the sediment give it a delta-like appearance in cross section (fig. 16). The Waukegan thins westward until it is only a few centimeters thick. The member is a soft, dark gray, sandy silt or clayey silt containing black beds and black mottling in most places where it is thick. The unit grades laterally into sandy near-shore sediments. The Waukegan has been dated in core 213 (interval 2 to 10.1 inches; 5 to 25.6 cm) at 3460 ± 210 radiocarbon years B.P. (ISGS-68), indicating that it is Holocene in age. Deposition of the Waukegan is continuing today, most of the sediment apparently being brought in by several small rivers that debouch along the eastern shore.

Lake Forest and Winnetka Members

The Lake Forest and Winnetka Members are brownish gray to gray silty clay and commonly contain many black beds and black mottling. They are somewhat irregular in thickness because they are in part facies of each other (Lineback et al., 1970). They thicken eastward and are included with the Waukegan Member on figure 15. The Lake Forest and Winnetka Members may grade laterally into a sand body near Benton Harbor at an elevation of 420 to 430 feet (128.0 to 131.1 m) (figs. 6, 16). The Winnetka and Lake Forest are overlain and overlapped by the delta-like Waukegan Member (fig. 16).

Sheboygan and South Haven Members

The Sheboygan Member consists of reddish brown clay and the South Haven Member of reddish gray clay. The two members have a similar distribution and are thickest—a combined thickness of up to 26.2 feet (8 m)—in the northwestern part of the southern lake basin (fig. 17). On the east side of the lake, the members are thin or absent, and they pinch out toward the western shore (figs. 18, 19). Parts of the red clay sequence grade laterally into sandy silt near Waukegan, and also along part of the mid-lake high (fig. 2). The elevation of the sandy silt is now about 290 to 310 feet (84.4 to 94.5 m) above sea level.

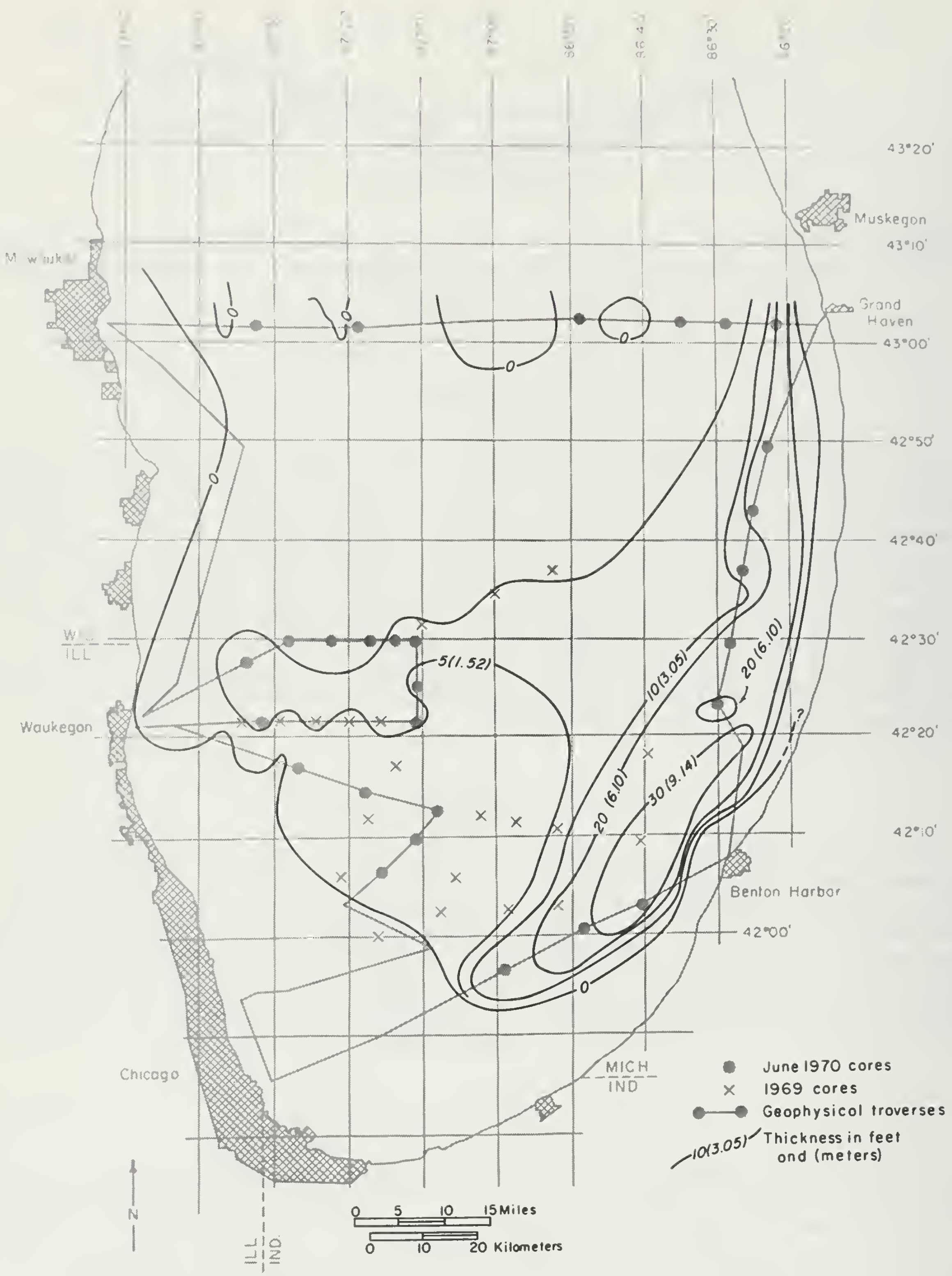


Fig. 15 - Thickness of the combined Waukegan, Lake Forest, and Winnetka Members of the Lake Michigan Formation, based on core and seismic data. These units are thickest in a band along the east side of the lake and in the center of the southern basin. Isopach interval is 10 feet (3.05 m), with an added 5-foot (1.52 m) isopach.

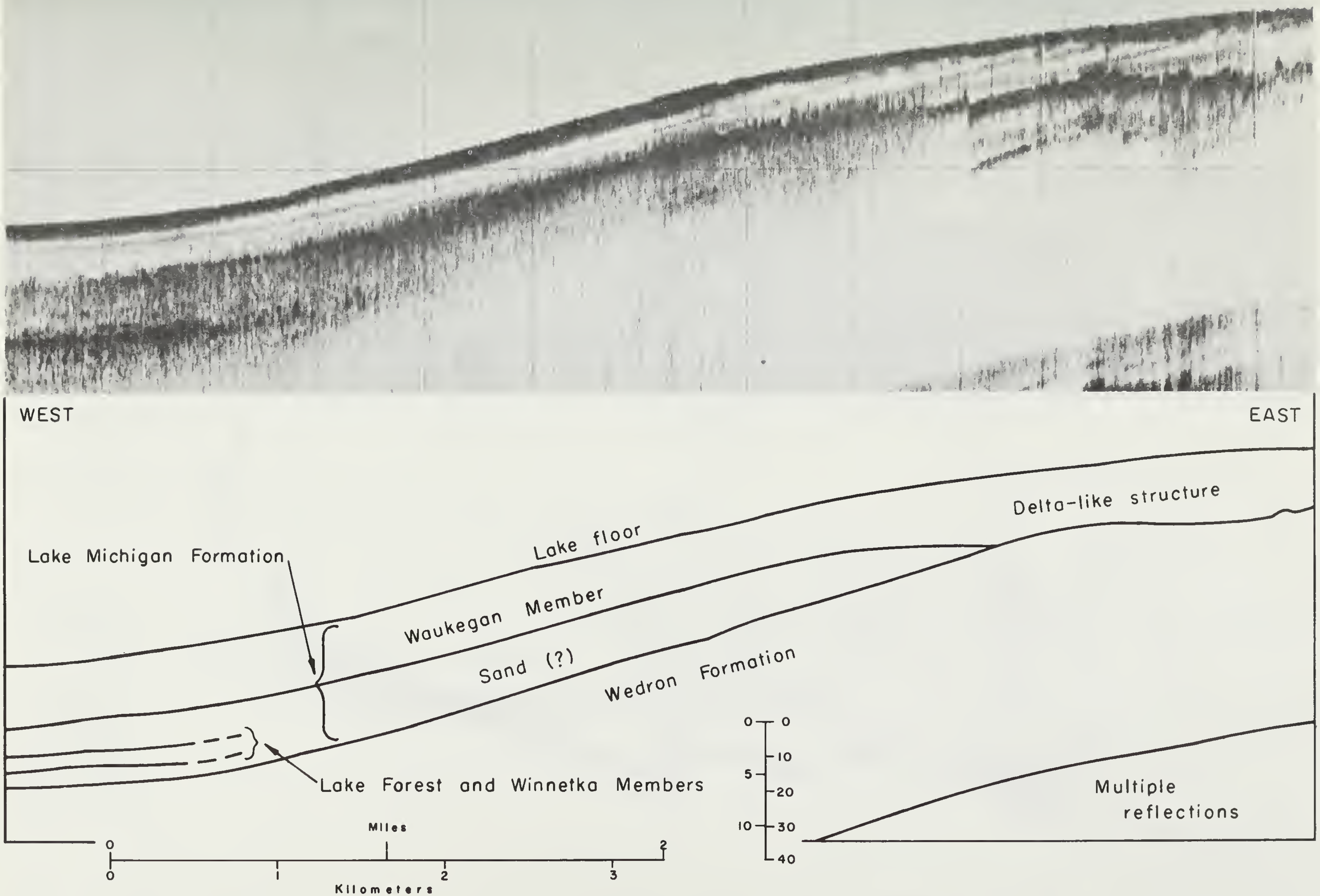


Fig. 16 - Seismic profile and interpretation of an area located 7 miles (11.3 km) southwest of Benton Harbor (see figure 10). The Lake Forest and Winnetka Members grade into a body of sand and are overlapped by the Waukegan Member that contains delta-like bedding. Bedrock reflections are not seen.

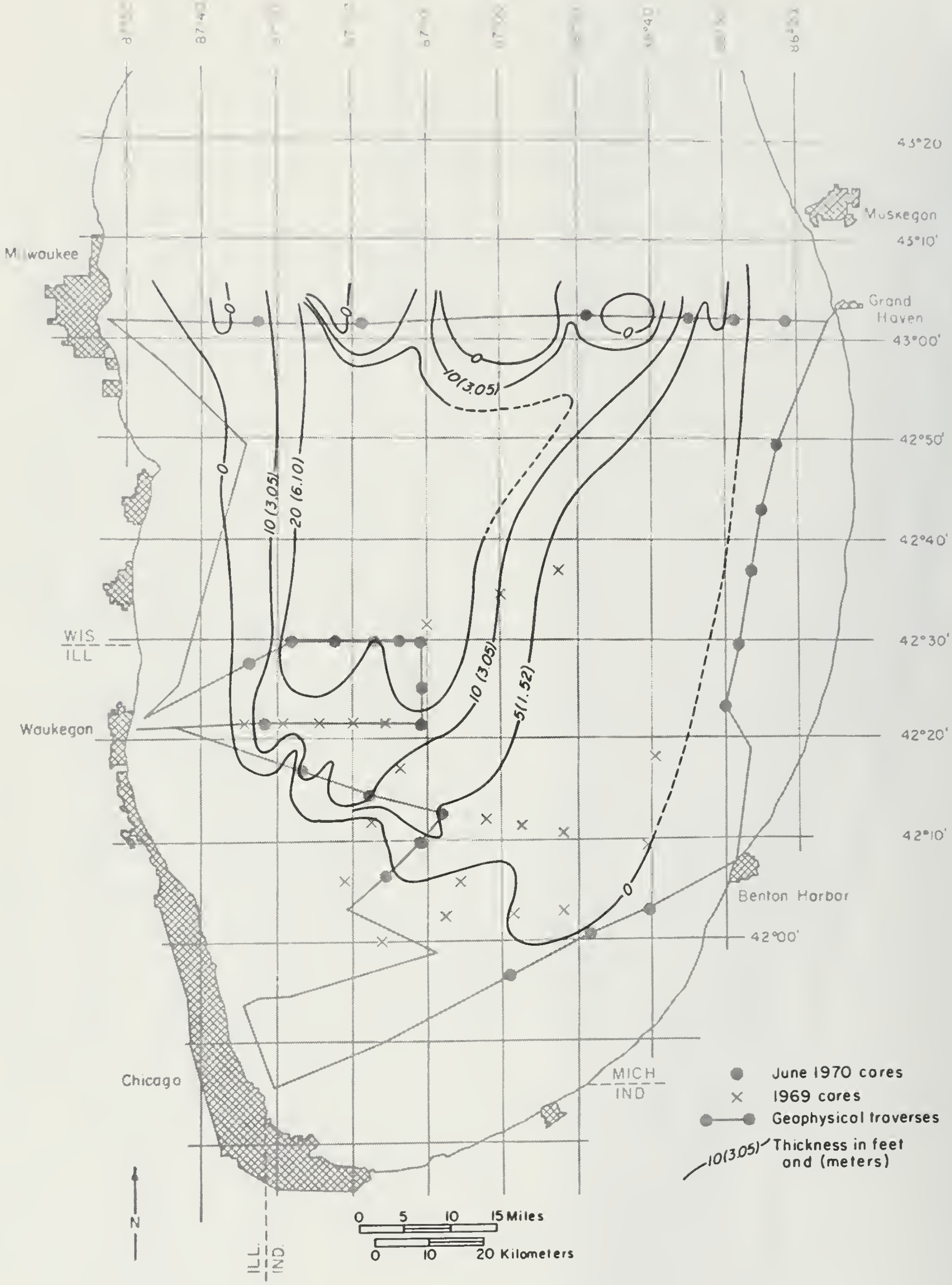


Fig. 17 - Thickness of the combined Sheboygan and South Haven Members of the Lake Michigan Formation in southern Lake Michigan, based on cores and seismic evidence. The two members are thickest in the northwestern part of the southern basin and pinch out shoreward. Isopach interval is 10 feet (3.05 m), with an added 5-foot (1.52 m) isopach.

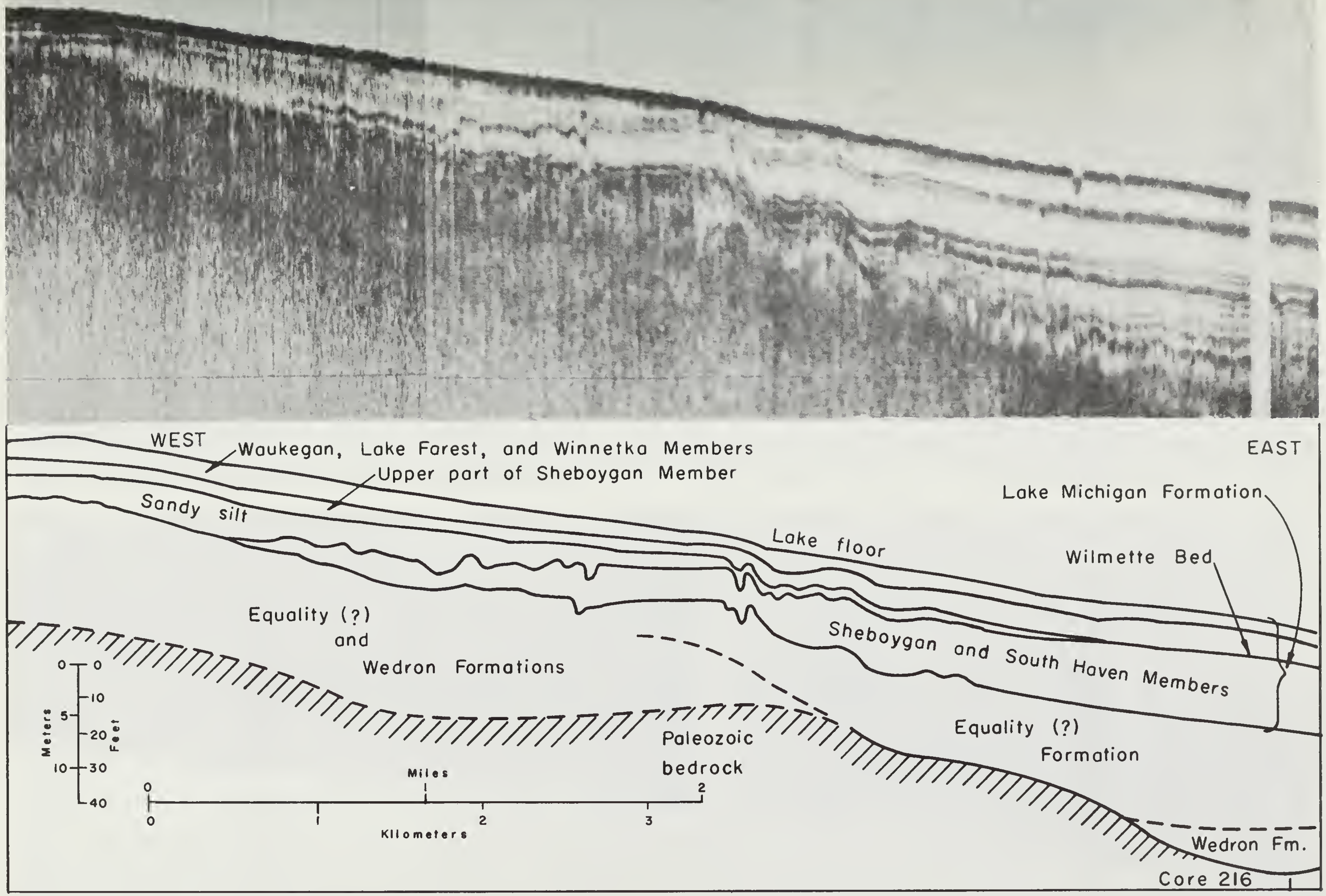


Fig. 18 - Seismic profile and interpretation of an area 15 miles (24.1 km) northeast of Waukegan (see figure 10). The lower part of the Sheboygan Member and the South Haven Member pinch out or are truncated shoreward by a sandy silt. The Wilmette Bed may grade laterally into the sandy unit or may be truncated by it. The upper members of the formation overlap the lower. The Lake Michigan Formation overlaps the layered unit tentatively assigned to the Equality (?) Formation.

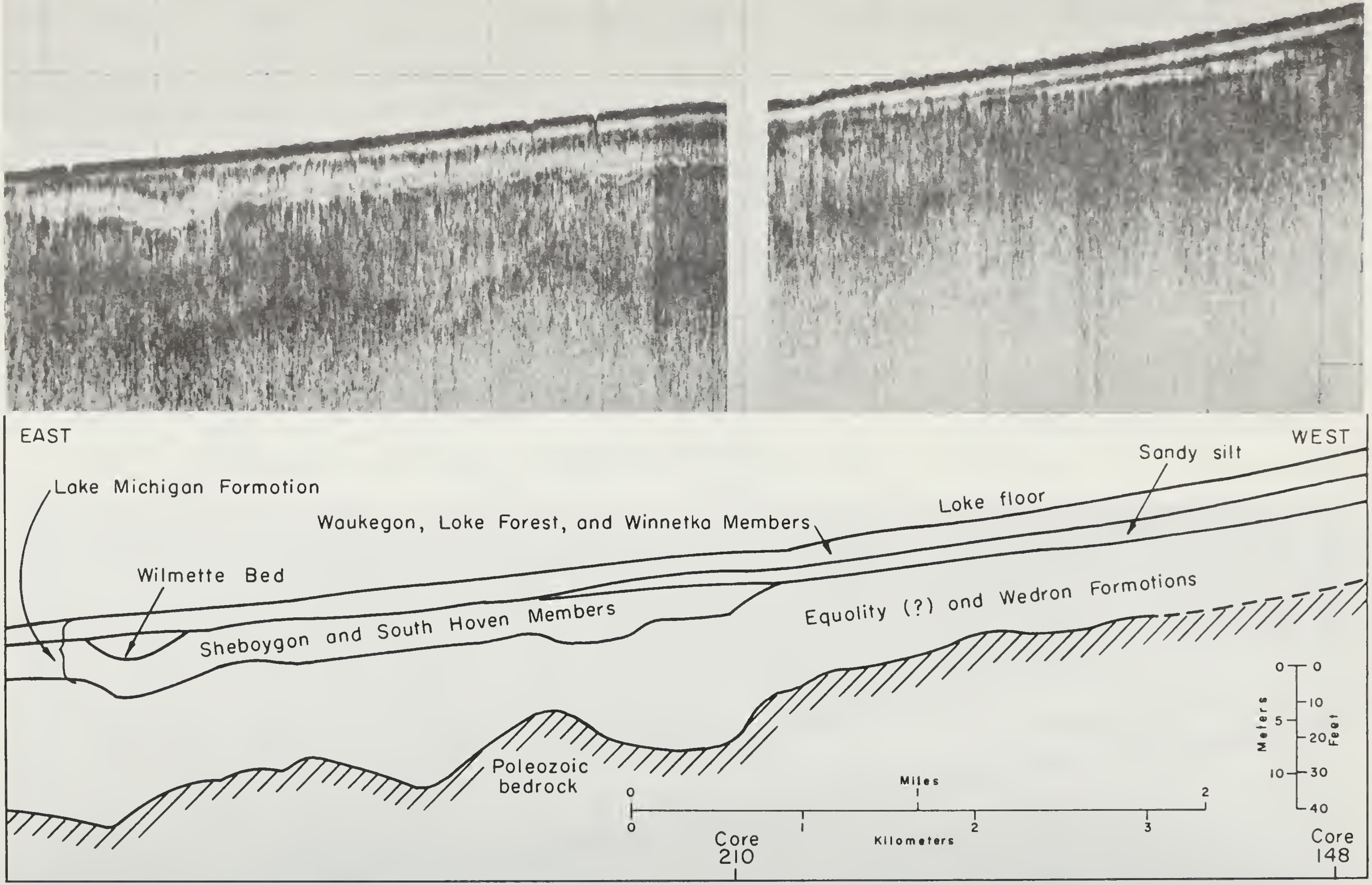


Fig. 19 - Seismic profile and interpretation of an area 10 miles (16.1 km) east of Waukegan (see figure 10). The Sheboygan and South Haven Members are truncated or pinch out shoreward against a sandy silt unit. The upper members of the Lake Michigan Formation overlap the lower and extend farther shoreward.

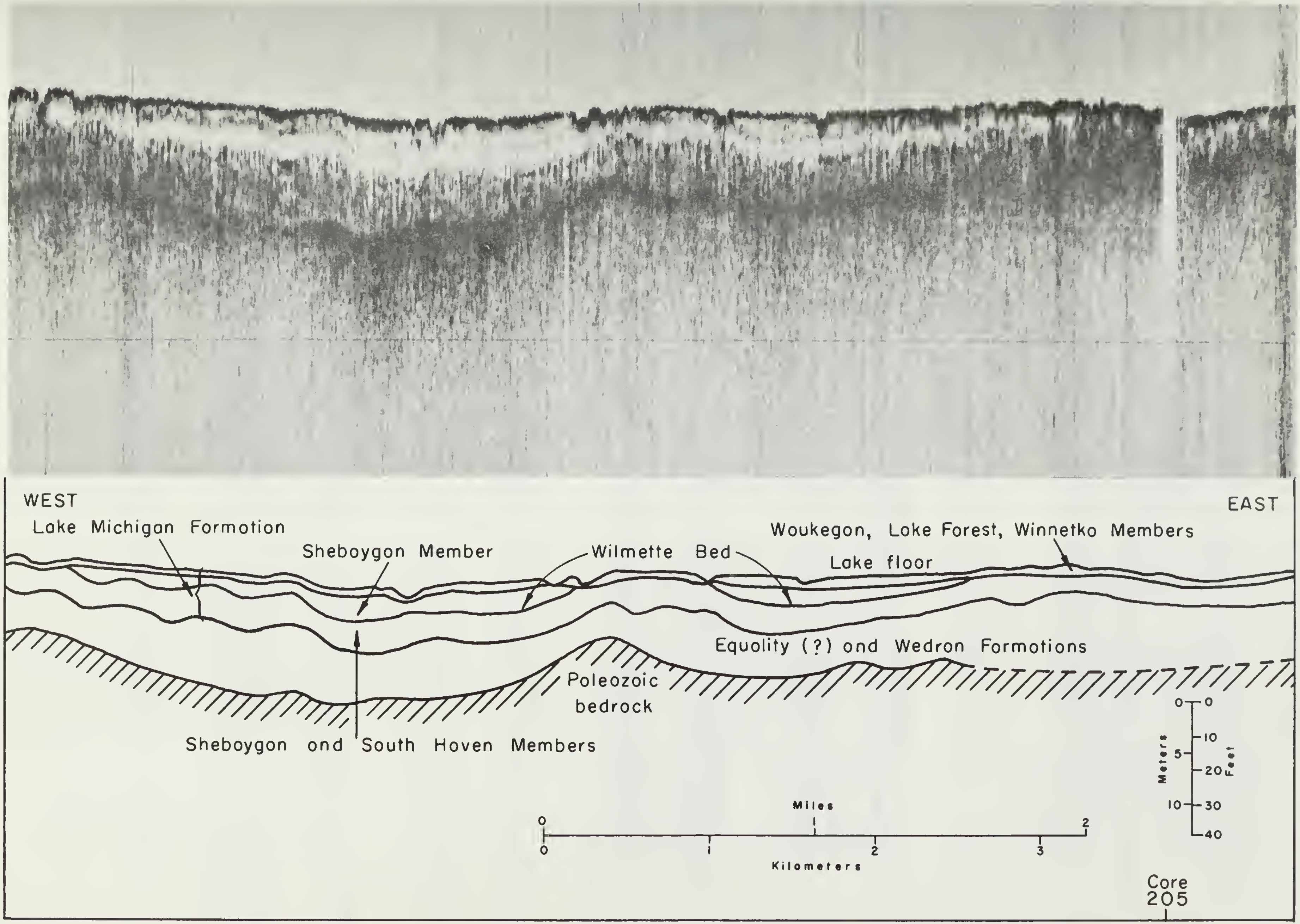


Fig. 20 - Seismic profile and interpretation of an area 30 miles (48.2 km) southeast of Waukegan (see figure 10). The Sheboygan and South Haven Members are truncated at topographic highs by upper members of the Lake Michigan Formation.

The Sheboygan Member contains a thin dark gray clay bed, the Wilmette Bed (Lineback et al., 1970). The Wilmette Bed is present in most of the area where red clays are found and can also be recognized as an acoustic horizon on several of the profiles (figs. 9, 18, and 19). Where present, the Wilmette ranges from 2.4 to 8.7 inches (6 to 22 cm) thick. It becomes sandy shoreward and may grade laterally into sandy silt near Waukegan (figs. 18, 19). The seismic profile extending from Chicago to Waukegan shows the Wilmette Bed and its enclosing red clay to be truncated over bedrock or till highs by the Winnetka or Lake Forest Members (fig. 20). A layer of sand 0.4 to 1.2 inches (1 to 3 cm) thick that contains fossil pelecypods occurs between the red clay and the overlying units at the unconformable contact (see cores 203, 204, 205, and 206 in appendix).

SUMMARY

Continuous, sub-bottom, high-resolution seismic profiling has proved a valuable addition to the sediment sampling program in southern Lake Michigan. With seismic information, acoustic reflection horizons can be related to lithologic units penetrated in cores, while profiles provide ready-made cross sections in the field for carrying correlations between cores and providing information on thickness, distribution, and structure of units.

Seismic profiles have been instrumental in determining the overlapping relations of the various units in the Lake Michigan Formation. Unconformities at the base of the South Haven, Winnetka, and Waukegan Members are well illustrated by the profiles. The seismic information also permitted the mapping of the thickness and topography of the glacial deposits as well as the topography of the bedrock surface, units that are rarely penetrated by gravity cores.

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APPENDIX

CORE DESCRIPTIONS

All cores described here are gravity cores, 1 7/8 inches (47 mm) in diameter, from southern Lake Michigan taken from the *R. V. INLAND SEAS*, June 1970. Description is by stratigraphic unit (fig. 1) and colors given are those of the standard Munsell notation.

CORE 177

Lat. 42°49.9'N, long. 86°23.8'W; water depth 234 feet (71.3 m).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Clay, silty, black, soft; trace of sand; 5 Y 2/1	4.0
2. Clay, silty, dark gray; trace of sand; black mottling throughout and some indistinct black beds; 5 Y 4/1	153.0

CORE 178

Lat. 42°43.1'N, long. 86°25.7'W; water depth 262 feet (79.9 m).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Clay, silty, sandy, dark gray; black beds; 5 Y 4/1	21.5
2. Clay, silty, dark gray; black mottling and many closely spaced black beds; a few fossils; 5 Y 4/1	110.5
Lake Forest Member	
3. Clay, gray; trace of sand; faint black beds in top and black mottling; a few fossils; 10 YR 5/1	165.7
Winnetka Member	
4. Clay, brown; trace of sand; a few fossils; 10 YR 5/3	181.0

CORE 179

Lat. 42°36.2'N, long. 86°27.3'W; water depth 246 feet (75.0 m).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Sand, silty, dark brown; 10 YR 3/3	4.2
2. Clay, silty, very dark gray grading downward into dark gray; trace of sand; black beds at 1 cm intervals and black mottling; 1 mm thick bed of shells at 171 cm; 5 Y 3/1 to 5 Y 4/1	306.0
Lake Forest Member	
3. Clay, gray, very stiff; faint black mottling; 10 YR 5/1	324.0

CORE 180

Lat. 42°29.4'N, long. 86°29.0'W; water depth 225 feet (68.6 m).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Clay, silty, black; trace of sand; 5 Y 2/1	2.0
2. Silt, dark gray, soft; trace of sand; black mottling and indistinct black beds; 5 Y 4/1	47.0
3. Clay, dark gray; trace of sand; black mottling and black beds; 5 Y 4/1	336.5

CORE 181

Lat. 42°22.4'N, long. 86°30.6'W; water depth 168 feet (51.2 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, black; trace of sand; 5 Y 2/1 . . . . . . 1.0
2. Clay, silty, dark gray; trace of fine sand; some very faint bedding; 5 Y 4/1 . . . . 60.0
3. Clay, dark gray; trace of sand; faint irregular beds; a few fossils; 5 Y 4/1 . 235.0

CORE 188

Lat. 42°03.2'N, long. 86°40.8'W; water depth 146 feet (44.5 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, black; 5 Y 2/1 . . 3.0
2. Silt, dark gray; bedding faint and indistinct; darker gray layers in lower part; 5 Y 4/1 . . . 175.0

CORE 189

Lat. 42°00.2'N, long. 86°49.1'W; water depth 187 feet (57.0 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, dark gray; grades downward into silty clay; trace of fine sand; faint bedding; some black mottling; 5 Y 4/1 . . . . . 319.0

CORE 190

Lat. 41°56.3'N, long. 86°59.6'W; water depth 188 feet (57.3 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Sand, olive-brown, fine grained; 2.5 Y 3/2 . . . . 2.3
2. Clay, silty, dark gray; very faint bedding; 5 Y 4/1 . . 77.5

Lake Forest Member

3. Clay, silty, dark gray; many faint black beds and black mottling; 1 mm shell layer at base; 10 YR 4/1 . 188.0

Winnetka Member

4. Clay, silty, brownish gray; faint black beds and mottling; 10 YR 4/2 . . . . . 294.2
5. Clay, silty, grayish brown; several thin beds of silt; fossils; some black mottling; 10 YR 5/2 . . . . . 310.0
6. Sand, gray; few fossils, layers of silty clay; 10 YR 5/1 . . . . 319.0

Wedron Formation
Wadsworth Member

7. Till, silty, clayey, gray, tough, plastic; trace of sand and pebbles; 5 Y 5/1. 124.0

CORE 204

Lat. 42°09.6'N, long. 87°12.5'W; water depth 266 feet (81.1 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, very dark grayish brown; trace of sand; some mottling of lighter brown; 10 YR 3/2 . . . . . 7.0
2. Clay, dark gray, soft, heavily mottled with black and darker gray; yellowish brown silt beds 1 mm thick at 14.0, 15.0, and 15.8 cm; 10 YR 4/1 . . . . 19.7

Lake Forest—Winnetka Members undifferentiated

3. Clay, grayish brown; black beds and black mottling; fossils; 10 YR 5/2 . . . . 67.5

4. Silt, sandy, brown; 7.5 YR 5/2 . . . . 69.0

Sheboygan Member

5. Clay, reddish brown clay; trace of gray mottling; fossils; 5 YR 5/3 . . . . 80.7

6. Clay, dark grayish brown; fault at base; 10 YR 4/2 . 89.0

7. Clay, reddish brown to reddish gray; trace of gray; disturbed by coring; 5 YR 5/3 to 5 YR 5/2 . . . 124.0

Wilmette Bed

8. Clay, gray, mottled with black; fault at base; 10 YR 5/1 . . . 132.0

9. Clay, reddish gray; 5 YR 5/2 . . . . 142.5

South Haven Member

10. Clay, reddish brown; some gray clay beds in lower part; 5 YR 5/3 . . . . . . 223.2

Equality (?) Formation
Carmi (?) Member

11. Clay, gray, thinly bedded, stiff, plastic; a few pebbles and trace of sand; some brown, sandy clay; 10 YR 5/1 to 5 Y 5/1 . . . 308.0

CORE 205

Lat. 42°12.9'N, long. 87°08.5'W; water depth 302 feet (92.0 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, dark yellowish brown; trace of sand; 10 YR 4/4 . . . . 1.0

2. Clay, silty, dark gray, soft; some black, gray, and brown mottling; 10 YR 4/1 . . . . 17.5

Lake Forest—Winnetka Members undifferentiated

3. Clay, gray to brownish gray; faint black beds and mottling; fossils; 10 YR 5/1 to 10 YR 5/2 . . . . 58.5

4. Silt, sandy, brown; fossils; 7.5 YR 5/2 . . . . 61.5

South Haven Member

5. Clay, reddish brown; faint bedding in lower part; 5 YR 5/3 . . . . 195.0

Equality (?) Formation
Carmi (?) Member

6. Clay, brown, with rock pebbles, clay pebbles, sand; dark gray sandy clay; 7.5 YR 5/2 and 5 Y 4/1 . . . . 229.0

Wedron Formation
Wadsworth Member

7. Till, sandy, clayey, silty, gray; pebbles; some brown clay-pebble conglomerate; 10 YR 5/1 . . . . 289.0

CORE 206

Lat. 42°14.8'N, long. 87°17.3'W; water depth 290 feet (88.4 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, clayey, dark brown, mottled lighter and darker brown; 10 YR 4/3 to 10 YR 5/3 . . . . 16.6

2. Clay, silty, yellowish brown, hard; 10 YR 5/4 . . 18.5

Lake Forest—Winnetka Members undifferentiated

3. Clay, silty, grayish brown, mottled with lighter gray and a trace of black; a few fossils; 10 YR 5/2 . . 44.8

4. Clay, sandy, brown; fossils; 7.5 YR 5/2 . . . . 48.6

Sheboygan Member

5. Clay, reddish gray to reddish brown; gray silt beds 1 mm thick near top; 5 YR 5/2 to 5 YR 5/3 . . . . 128.0

Wilmette Bed

6. Clay, dark gray, mottled black; fault in middle with slice of reddish brown clay; 5 Y 4/1 . . . . 149.5

7. Clay, reddish brown to reddish gray; some black mottling and one black bed at 183 cm, dipping at 45° angle; 5 YR 5/3 to 5 YR 5/2 . . . . 203.0

South Haven Member

8. Clay, reddish brown; faint bedding; 5 YR 5/4 to 5 YR 5/3 . . . . 308.5

CORE 207

Lat. 42°17.0'N, long. 87°26.2'W; water depth 265 feet (80.8 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, sandy, dark grayish brown to dark brown; fossils; yellowish brown hard silt layers at 6.5, 10.2, and 15.0 cm; 10 YR 3/2 to 10 YR 4/3 . . . . 15.5

Lake Forest—Winnetka Members undifferentiated

2. Silt, clayey, gray; trace of sand; black mottling; fossils; 10 YR 5/1 . . . 51.0

South Haven Member

3. Clay, reddish brown to reddish gray; some faint bedding; 5 YR 5/4 to 5 YR 5/2 . . . . 341.0

CORE 210

Lat. 42°21.8'N, long. 87°32.1'W; water depth 260 feet (79.2 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Sand, silty, dark yellowish brown; 10 YR 4/4 . . . . . . 0.5

2. Silt, sandy, very dark gray, soft; 10 YR 3/1 . . . . . . 7.0

Lake Forest Member

3. Silt, clayey, very dark gray; trace of sand; black beds and mottling; 10 YR 3/1 . . . . 28.2

Winnetka Member

4. Clay, grayish brown; many black beds and black mottling; becomes browner downward; 10 YR 5/2 . . . . 156.0

5. Clay, brown; gray silt beds; 7.5 YR 5/2 . . . . 190.0

6. Clay, sandy, grayish brown; bed of fossils at 208 cm; 10 YR 5/2 . . . . 211.5

South Haven Member

7. Clay, reddish brown; 5 YR 5/3 . . . . 321.5

CORE 211

Lat. 42°21.8'N, long. 87°10.8'W; water depth 387 feet (118.0 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, sandy, very dark gray, very soft; black mottling; 10 YR 3/1 . . . . 15.0

Lake Forest Member

2. Clay, silty, dark gray; black beds and black mottling; 10 YR 3/1 to 10 YR 5/1 . . . . 55.5

Winnetka Member

3. Clay, grayish brown; black beds and mottling; fossils; 10 YR 5/2 . . . . 96.0

Sheboygan Member

4. Clay, brown; a little black mottling; 7.5 YR 5/2 . . . . 121.7

Wilmette Bed

5. Clay, dark gray; trace of black mottling; 5 Y 4/1 . . . . 132.0

6. Clay, reddish brown; 5 Y 5/3 . . . . 164.0

South Haven Member

7. Clay, reddish gray; faint bedding; 5 YR 5/2 . . . . 184.0

CORE 212

Lat. 42°25.8'N, long. 87°10.8'W; water depth 412 feet (125.6 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)

Waukegan Member

1. Silt, very dark gray, soft; black beds; dated at 3460 ± 210 radiocarbon years B.P.; 5 Y 3/1 . . . . 25.6

Lake Forest Member

2. Clay, silty, light gray; black mottling; fossils; 10 YR 6/1 . . . . 41.5

Sheboygan Member

3. Clay, brown; a little black mottling; 7.5 YR 5/2 . . . . 101.0

Wilmette Bed

4. Clay, dark greenish gray; faint black mottling; 5 GY 4/1 . 122.0

5. Clay, dark grayish brown; laminations; 10 YR 4/2 . 130.4

6. Clay, reddish brown, with slightly browner bands; 5 YR 4/4 to 5 YR 5/3 . . 189.0

South Haven Member

7. Clay, reddish brown; very faint bedding; 5 YR 5/3 . 273.5

CORE 213

Lat. 42°29.5'N, long. 87°10.8'W; water depth 455 feet (138.7 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)

Waukegan Member

1. Silt, black, grading downward into dark gray, very soft; black beds and mottling; 10 YR 2/1 to 10 YR 3/1 . . . . 66.1

Lake Forest Member

2. Clay, gray clay; black beds; 10 YR 5/1 . . . . . . 151.5

Winnetka Member

3. Clay, dark grayish brown; black beds and mottling; 10 YR 4/2 . . . . 226.0

Sheboygan Member

4. Clay, brown; some faint black mottling; 7.5 YR 5/2 . . . . 284.6

5. Clay, reddish gray; trace of black mottling; 5 YR 5/2 . . . . 323.6

Wilmette Bed

6. Clay, dark gray; black mottling; some mottling of lighter gray; 5 Y 4/1 . . . . 334.3

7. Clay, gray; 10 YR 5/1 . . . 338.2

CORE 214

Lat. 42°29.5'N, long. 87°16.7'W; water depth 405 feet (123.4 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)

Waukegan Member

1. Silt, very dark gray, soft; black beds and mottling; 5 Y 3/1 . . . . . . 27.5

Lake Forest Member

2. Clay, light gray; black beds and mottling; becomes darker gray in lower part; 10 YR 6/1 to 10 YR 5/1 . . 75.0

Sheboygan Member

3. Clay, pinkish gray; trace of black mottling; 7.5 YR 6/2 to 7.5 YR 5/2 . . . 181.6

Wilmette Bed

4. Clay, gray; black mottling; 5 Y 5/1 . . . . 194.5

5. Clay, gray; trace of black mottling; 10 YR 5/1 . . . 200.5

6. Clay, reddish brown; bands of browner clay; 5 YR 5/3 . . . . 232.0

South Haven Member

7. Clay, reddish brown; homogeneous; 5 YR 5/3 . . . . 312.2

CORE 215

Lat. 42°29.5'N, long. 87°22.5'W; water depth 360 feet (109.7 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)

Waukegan Member

1. Clay, very dark gray; some black beds and mottling; 10 YR 3/1 . . . 18.4

Lake Forest Member

2. Clay, gray; some black beds and mottling; 10 YR 5/1 . . . . 32.3

Winnetka Member

3. Clay, grayish brown to brown; black beds and mottling; fossils; 10 YR 5/2 to 10 YR 5/3 . . . . 102.7

Sheboygan Member

4. Clay, brown; trace of black mottling; 7.5 YR 5/2 . . . . 159.2

Wilmette Bed

5. Clay, dark gray; black mottling; 5 Y 4/1 . . . 175.3

6. Clay, dark grayish brown; 10 YR 4/2 . . . . 181.0

7. Clay, reddish brown and brown in alternating bands; 5 YR 4/3 and 7.5 YR 4/2 . . 227.0

South Haven Member

8. Clay, reddish brown; faint bedding; 5 YR 4/3 . . . . . 291.5

CORE 216

Lat. 42°29.5'N, long. 87°28.5'W; water depth 312 feet (95.1 m).

Pleistocene Series	Depth
Lake Michigan Formation	(cm)

Waukegan Member

1. Silt, sandy, dark yellowish brown; 10 YR 4/4 . . . 1.5

2. Silt, very dark gray; trace of sand; 10 YR 3/1 . . . . 4.2

Winnetka Member

3. Clay, grayish brown; many black beds and black mottling; 10 YR 4/2 to 10 YR 5/2 . . . . 109.5

Sheboygan Member

4. Clay, brown; trace of black mottling in upper part; faint laminations; some reddish brown and grayish brown; 7.5 YR 5/2 . . . . . 285.7

Wilmette Bed

5. Clay, gray; black mottling; 5 Y 5/1 . . . . 300.0

6. Clay, reddish gray to reddish brown; 5 YR 4/2 to 5 YR 5/3 . . . . 330.0

CORE 217

Lat. 42°27.5'N, long. 87°33.6'W; water depth 258 feet (78.6 m).

Pleistocene Series — Depth (cm)

Lake Michigan Formation

Waukegan Member

1. Silt, sandy, yellowish brown, firm; 10 YR 5/4 . . . 3.6
2. Clay, sandy, very dark gray, very soft; trace of black mottling; 10 YR 3/1 . . . . 17.7

Winnetka Member

3. Clay, grayish brown; trace of sand and fossils; black beds and mottling; 10 YR 5/2 . . . . 164.3

Sheboygan Member

4. Clay, brown in upper part, reddish brown in lower part; trace of black mottling near top; 7.5 YR 5/2 to 5 YR 4/4 . . . . 285.6

CORE 234

Lat. 43°[illegible].8'N, long. 87°32.4'W; water depth 282 feet (86.0 m).

Pleistocene Series — Depth (cm)

Lake Michigan Formation

Waukegan Member (?)

1. Sand, silty, dark brown; fossils; 7.5 YR 4/4 . . . 1.0
2. Clay, silty, brown; faint bedding; small brown speckles; 7.5 YR 5/4 . . . . . 22.5

Sheboygan Member

3. Clay, reddish brown; 5 YR 5/3 . . . . 40.2

Wilmette Bed

4. Clay, dark gray to grayish brown; black mottling; 5 Y 4/1 to 10 YR 4/2 . . . . . . 54.0

5. Clay, reddish brown; alternating laminations of redder and browner clay; 5 YR 5/4 . . . . 95.0

South Haven Member

6. Clay, reddish brown; homogeneous; 5 YR 5/3 . . . . . 232.7

Unnamed formation

7. Till (?), clayey, silty, brown, plastic; clay pebbles; 7.5 YR 5/2 . . . . . 257.0
8. Clay, sandy, brown; clay pebbles; deformed bedding; 7.5 YR 5/2 . . . . 278.0

CORE 235

Lat. 43°02.2'N, long. 87°18.0'W; water depth 290 feet (88.4 m).

Pleistocene Series — Depth (cm)

Lake Michigan Formation

Waukegan Member (?)

1. Sand, brown; fossils; 7.5 YR 5/4 . . . . 1.5
2. Clay, yellowish red, mottled with dark brown specks; dark brown silt layers 1 mm thick at 16.9 and 24.2 cm; 5 YR 4/6 . . . . 26.2

Sheboygan Member

Wilmette Bed

3. Clay, grayish brown, grading downward into gray; 2.5 Y 4/2 to 10 YR 4/1 . . . . 38.2

4. Clay, reddish brown; a few beds of more brownish gray; 5 YR 5/4 . . . . 75.3

South Haven Member

5. Clay, reddish brown; indistinct bedding; more homogeneous than Sheboygan; 5 YR 5/3 . . . . 237.7

Equality (?) Formation

Carmi (?) Member

6. Silt, sandy, lacustrine, dark grayish brown; 2.5 Y 4/2 . . . . 249.0

7. Conglomerate, clay-pebble, brown; 7.5 YR 5/2 . . . . 299.0

8. Clay, sandy, brown; 7.5 YR 5/2 . . . . 305.5

CORE 237

Lat. 43°02.7'N, long. 86°49.0'W; water depth 323 feet (98.5 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member (?)

1. Clay, silty, brown; trace of sand; fossils; 10 YR 5/3 . . . . 3.2

South Haven Member

2. Clay, reddish brown to reddish gray; 5 YR 5/4 to 5 YR 5/2 . . . . 186.6

Equality (?) Formation
Carmi (?) Member

3. Clay, grayish brown; trace of sand; a few clay pebbles; 10 YR 5/2 . . . . . 271.2

Unnamed formation

4. Till, silty, clayey, brown, plastic; trace of sand; 7.5 YR 5/2 . . . . 313.8

5. Clay, brown, soft; 7.5 YR 5/2 . . . . 319.5

CORE 238

Lat. 43°02.9'N, long. 86°34.5'W; water depth 330 feet (110.6 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member (?)

1. Silt, sandy, dark yellowish brown with light and dark brown mottling; 10 YR 4/4 . . . . 22.5

2. Sand, pinkish gray; 7.5 YR 6/2 . . . . 28.5

South Haven Member (?)

3. Clay, reddish brown; 5 YR 5/4 . . . . 33.7

Unnamed formation

4. Till, silty, clayey, brown, soft, plastic; trace of rock pebbles and clay pebbles; 7.5 YR 5/2 . . . . 107.2

Wedron Formation (?)
Wadsworth Member (?)

5. Clay, grayish brown; distorted bedding; 10 YR 5/2 . 190.0

6. Till, sandy, silty, clayey, grayish brown; 10 YR 5/2 . 201.5

CORE 239

Lat. 43°03.0'N, long. 86°29.4'W; water depth 312 feet (95.1 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, sandy, yellowish brown, mottled with brown; 10 YR 5/4 . . . . 43.0

South Haven Member

2. Clay, brown; silt; 7.5 YR 5/4 . . . . 62.0

Unnamed formation

3. Till, silty, clayey, brown; trace of pebbles and sand; some interbedded clay; 7.5 YR 5/2 to 5 YR 5/3 . . . . 183.0

CORE 241

Lat. 43°03.0'N, long. 86°22.3'W; water depth 212 feet (64.6 m).

Pleistocene Series — Depth (cm)
Lake Michigan Formation
Waukegan Member

1. Silt, sandy, dark gray; black beds and mottling; 5 Y 4/1 . . . . 171.0

2. Clay, silty, dark grayish brown; 2.5 Y 4/1 . . . . . 177.2

3. Silt, sandy, dark gray; black beds and mottling; 5 Y 4/1 . . . . 258.3

4. Clay, silty, grayish brown; 2.5 Y 5/2 . . . . . 266.0

CORE 368

Lat. 42°29.5'N, long. 87°12.8'W; water depth 451 feet (137.5 m).

	Depth (cm)
Pleistocene Series	
Lake Michigan Formation	
Waukegan Member	
1. Silt, sandy, very dark grayish brown, firm; 2.5 Y 3/2	3.0
2. Silt, black, soft; 5 Y 2/1	23.0
3. Silt, clayey, dark gray, soft; black beds and mottling; 5 Y 4/1	75.2
Lake Forest Member	
4. Clay, gray; black beds and mottling; 10 YR 5/1	198.4
Winnetka Member	
5. Clay, grayish brown; fewer black beds than Lake Forest; 10 YR 5/2	279.0
Sheboygan Member	
6. Clay, brown; some black mottling; 7.5 YR 5/2 . . .	384.5
Wilmette Bed	
7. Clay, gray; black bed at top and black mottling; 5 Y 5/1	396.5
8. Clay, brownish gray; faint bedding; 10 YR 5/2	408.0
9. Clay, reddish brown; bands of browner clay; 5 YR 5/3 .	474.0
South Haven Member	
10. Clay, reddish brown, more homogeneous than above; 5 YR 5/3	493.0

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